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Green (Del) Associates, Inc., Woodburn, OR

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Task 3
Wood Fuel Use Projection

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This report analyzes trends in wood fuel use within the city limits of Seattle and Spokane (Washington) and in the greater Portland (Oregon) metropolitan area. Short-term (through 1985) and long-term (through 2000) trend projections are presented. Short-term projections were made based on volumes of firewood removed from the nearest national forest(s) and average heating season nephelometer light scattering coefficient (Bscat), normalized for temperature and meteorological effects for two sites in the Portland areas and one site in SEattle.

For long-term projections of wood fuel use, a state-of-the-art model was adapted and applied to simulate wood fuel use during 1970-2000. This model calibrated well against limited available data on actual wood use. The model projects increasing or decreasing wood fuel use based primarily upon the magnitude of potential fuel cost savings from heating with wood versus other fuels.

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RESIDENTIAL WOOD COMBUSTION STUDY

TASK 3

WOOD FUEL USE PROJECTION

RESIDENTIAL WOOD COMBUSTION STUDY
TASK 3
WOOD FUEL USE PROJECTION

-FINAL REPORT-

PREPARED BY:

William T. Greene,President (Task 3 Manager)
Solutions for Energy and Environment, Inc. (SE2, Inc.)
1615 NW 23rd Avenue
Portland, Oregon 97210

AND

Robert L. Gay Ph.D., Consultant
4423 SW Hamilton Terrace
Portland, Oregon 97201

PREPARED FOR:

DEL GREEN ASSOCIATES, INC.
ENVIRONMENTAL TECHNOLOGY DIVISION
1535 N. Pacific Highway
Woodburn, Oregon 97071

Under Contract No. 68-02-3566 FROM:

U.S. ENVIRONMENTAL PROTECTION AGENCY
Region X
1200 Sixth Avenue
Seattle, Washington 98101

Task Manager

Wayne Grotheer

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THEY ARE LISTED BELOW FOR YOUR CONVENIENCE.

EPA 910/9-82-089a	Residential Wood Combustion Study Task 1 - Ambient Air Quality Impact Analysis
EPA 910/9-82-089b	Task 1 - Appendices
EPA 910/9-82-089c	Task 2A - Current & Projected Air Quality Impacts
EPA 910/9-82-089d	Task 2B - Household Information Survey
EPA 910/9-82-089e	Task 3 - Wood Fuel Use Projection
EPA 910/9-82-089f	Task 4 - Technical Analysis of Wood Stoves
EPA 910/9-82-089g	Task 5 - Emissions Testing of Wood Stoves Volumes 1 & 2
EPA 910/9-82-089h	Task 5 - Emissions Testing of Wood Stoves Volumes 3 & 4 (Appendices)
EPA 910/9-82-089i	Task 6 - Control Strategy Analysis
EPA 910/9-82-089j	Task 7 - Indoor Air Quality

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EXECUTIVE SUMMARY

This report analyzes trends in wood fuel use within the city limits of Seattle and Spokane (Washington) and in the greater Portland (Oregon) metropolitan area. Short-term (through 1985) and long-term (through 2000) trend projections are presented.

The following trend parameters were used in the short-term projections:

1. Volumes of firewood (cords/year) removed from the nearest national forest(s); and
2. Average heating season nephelometer light scattering coefficient (Bscat), normalized for temperature and meteorological effects for two sites in the Portland area and one site in Seattle.

Other short-term trend parameters were considered but not used because of inadequate data (not enough years of data for trend analysis, not directly linked to levels of woodburning, missing data). These include the following:

1. Various surveys of household wood use
2. Sales of woodburning appliances
3. Census data
4. Air quality data including coefficient of haze, soiling index, benezene soluble particulate extractions, organic and total carbon measurements on particulate (HiVol) samples, chemical mass balance (CMB), and carbon-14 measurements on particulate samples.

For all three areas, the best estimate of recent (1978-1981) short-term trends was a 6-8% annual average increase in wood fuel use. At this annual rate of increase, wood fuel use would grow by 34-47% from 1980 to 1985.

For long-term projections of wood fuel use, a state-of-the-art model was adapted and applied to simulate wood fuel use during 1970 - 2000. This model calibrated well against limited available data on actual wood use.

Historical wood usage between 1970 and 1980 is well predicted by the model. The model's predictions for 1981-83 are consistent with the short-term trend analysis and projections in Section II of this report and provided reasonable results in limited sensitivity tests.

The model's input data and assumptions take into account estimated costs of wood and alternative fuels, population and household growth projections, household heating requirements, area mix of home heating fuels, and other factors influencing residential wood fuel use. A major shortcoming of the model is that the effect of increasing competing demands on wood supplies is not taken into account.

The model projects increasing or decreasing wood fuel use based primarily upon the magnitude of potential fuel cost savings from heating with wood versus other fuels. This drives the simulated installation of new wood burning devices and also determines the assumed rate of capacity utilization (percent of total possible usage) of wood heating systems.

A major modification of the model was made to include fireplace wood use. The original model only projected wood fuel use in stoves and furnaces. However, survey data for Portland indicated that over half of the firewood used in 1978-79 was burned in fireplaces. Thus, the modified model predicts wood fuel use (cords/year) for stoves, furnaces, and fireplaces, and their total. The model is fully documented in Appendix A (and Reference 15), including description of input data and assumptions.

Table 1 summarizes the model's best estimates for long-term wood fuel use for Portland, Seattle and Spokane for 1980 - 2000 and corresponding particulate emissions. Projections were made for the city limit area of

TABLE 1

Best Estimate Projections of Residential Wood Fuel Use (10^3 cords/year) for Portland, Seattle, Spokane (1980-2000) and Corresponding Particulate Emissions (10^3 tons TSP/yr)

Year	Number of Households	Stove/Furnace Wood Usage	Fireplace Wood Usage	Total Wood Usage	Total Particulate Emissions
PORTLAND METROPOLITAN AREA					
1980	471,850	150	190	340	9.3
1985	537,800	240	190	430	12.8
1990	603,750	240	170	410	12.5
1995	669,700	300	150	450	14.5
2000	735,650	340	140	480	15.9
CITY OF SEATTLE					
1980	220,000	45	110	155	3.7
1985	246,180	85	100	185	5.1
1990	269,720	85	100	185	5.1
1995	294,360	90	100	190	5.3
2000	323,180	85	100	185	5.1
CITY OF SPOKANE					
1980	70,920	28	93	121	2.7
1985	77,940	42	84	126	3.1
1990	83,960	45	81	126	3.2
1995	90,910	51	78	129	3.4
2000	98,860	54	75	129	3.4

Seattle and Spokane, and the greater Portland metropolitan area because input data were more readily available.

For the Portland metropolitan area, total wood usage is projected to increase at an annual rate of 6.5% between 1980 and 1983, 0% between 1984 and 1988, and 1.6% per year between 1990 and the year 2000. This represents a 41% increase in total wood fuel use between 1980 and 2000 resulting from a 127% increase in wood usage in stoves and furnaces and a 26% decrease in fireplace wood usage during 1980 - 2000. Because stoves emit more than twice as much particulates per ton of wood burned than fireplaces, the 41% increase in total wood usage represents about a 71% increase in particulate emissions by the year 2000 with more than half occurring by 1985. The increase in particulate emissions may well be less than projected if more efficient stoves become available and public education campaigns on proper burning methods are successful.

For Seattle residences, total wood fuel use is projected to increase by 26% between 1980 and 1985. Wood fuel use is projected to peak around 1995 and decrease slightly in the following five years. Only a 19% increase in total usage is projected between 1980 and the year 2000. This corresponds to a 38% increase in particulate emissions between 1980 and 2000 based on a projected 89% increase in stove wood usage and a 9% decrease in fireplace wood usage. These projections are for residential wood combustion (RWC) within Seattle limits only.

For residences within the Spokane city limits, total wood fuel use is projected to increase by 4% between 1980 and 1985. A 7% increase in total wood usage is projected between 1980 and the year 2000. RWC particulate emissions are projected to increase by 26% between 1980 and the year 2000 based on a 93% increase in stove wood usage and a 19% decrease in fireplace wood usage.

These long-term wood fuel use projections represent most probable (base case) input data. No alternative input data or assumptions have been tried other than model calibration runs and limited sensitivity testing. Additional model runs could test (1) alternative input data, e.g., revised projections of electricity costs under the Northwest Electric Power Planning and Conversation Act of 1980 (PL 96-501); or (2) effects of certain RWC control strategies, e.g., weatherization to lower average home heating requirements or tax credits for installing cleaner wood stoves, etc.

The future prices of both wood and the conventional fuels have major impacts on the projected levels of residential woodburning. For conventional fuels, projected prices were furnished by the Bonneville Power Administration and the Oregon Department of Energy. These cost projections show oil, gas, and electricity approximately doubling in real cost between 1980 and 2000, compared to about a 50% increase in real cost for wood during the same period. Changes in these projected costs, as well as the possible substantial increase in residential coal combustion, could alter the wood use projections significantly. As an example, changing the wood price increase from +2%/year to +5%/year results in a net decrease in residential wood combustion. These projections should be used with the understanding that major deviations in fuel costs will have a substantial impact on the levels of residential wood combustion.

I. INTRODUCTION

A. PURPOSE

The primary purpose of Task 3 is to project trends in residential wood fuel use through the year 2000 for three cities in the Pacific Northwest: Portland, Oregon, and Seattle and Spokane in Washington. Projections for the years 1985, 1990, and 1995 will be estimated in the process of formulating a best estimate for the year 2000. Shorter term trends, based on data describing recent wood fuel use and other trend factors, will also be examined where sufficient data is available.

The projected trends in residential wood fuel use from Task 3 will be used in Task 2A to project future ambient air quality impacts from residential wood burning. The projections should assist air quality agencies in estimating the severity of future impacts from wood burning. The modeling approach used to project long-term trends will also indicate how important factors can interact in determining future wood burning impacts, such as the estimated price of wood versus conventional fuels.

B. SUMMARY OF TECHNICAL APPROACH

A thorough literature review was conducted to locate information on previous projections of residential wood fuel use. Extensive contact was made with knowledgeable individuals in public agencies, private institutions and businesses, universities, and associations. Most projections were of national wood fuel use. Transportation costs are a major factor in residential wood combustion, which tends to make national trend data of minimal use in predicting trends for specific localities. For example, two cities only 200 miles apart can have very different residential wood burning patterns because of the differences in wood availability and cost.

Only two projections were for Pacific Northwest areas - one by the Bonneville Power Administration (BPA) and the other by the Oregon Department of Environmental Quality (ODEQ). The BPA study covered only electrically heated homes in the Pacific Northwest. The ODEQ study used survey results from the 1978-79 heating season in the Portland-Vancouver area, and projected residential wood combustion through 1987 using expected population growth and trend data for wood cutting permits.

A particularly relevant study of residential wood fuel use in New England was recently completed at Dartmouth College. It provided the best critique of previous projections of wood fuel use in the U.S. The Dartmouth study also provided a methodology (model), which was adapted and used in this study to project wood fuel use trends for the Portland, Seattle, and Spokane areas. The model's input data and assumptions take into account those estimated costs of wood and alternative fuels, population and household growth projections, household heating requirements, area mix of home heating fuels, and other factors influencing residential wood fuel use.

Pacific Northwest input data for these and other model variables included the following:

- historical and projected costs for conventional fuels such as oil, gas and electricity
- historical and projected fractions of households that rely on oil vs. gas or electricity as primary heating fuels (used to derive average conventional fuel heating costs)
- historical and projected household heating requirements
- past and projected wood costs (used to assess savings potential from heating with wood compared with conventional fuels)

- assumed wood heating installation costs
- assumed inconvenience costs of wood heating
- assumed rates of consumer responses to install wood heating systems based on the expected length of the investment payback period

The model's estimates for the years 2000, 1995, 1990 and 1985 are presented as this study's "best estimates" of long-term wood fuel use trends. A tentative estimate of the uncertainty in the model projections is made based upon a limited sensitivity analysis of major variables. Model projections are compared (in Section III) with the national wood use trends, the two previous wood use projections in the Pacific Northwest by BPA and DEQ, and regional population and household growth projections.

Short-term trends for the three Pacific Northwest cities were estimated using several different types of information, including:

1. Direct measures of firewood use, including volumes of firewood removed from public and private lands under firewood cutting permits and household surveys of firewood use.
2. Direct measures of RWC effects--specific ambient air quality impacts of RWC represented by nephelometer data.
3. Other data sources considered but not used in trend calculations included data on the sales of wood burning appliances and other census and air quality data. Air quality data used was normalized for heating season severity (based on heating degree days) and meteorology (based on surface wind speed). Trend data were plotted. Regression lines of best fit for these plots were used to describe annual rate of change in trend parameters from 1982-85 for short-term trend estimates.

Previous chemical mass balance and carbon-14 analyses of particulate monitoring samples, which are considered reliably specific indicators of the ambient air quality impacts from residential wood combustion were examined. There were not enough of these to do trend analysis. However, their magnitudes and location are discussed.

The short-term trend estimates confirm what was already known -- that residential wood combustion has increased substantially in the last few years. However, the long-term trends projected for wood fuel use are likely to be more reliable bases for projecting air quality impacts from residential wood burning for several reasons:

- Penetration into the marketplace of a new technology, almost always follows an S - shaped curve with increasing penetration rates at first. Depending on the stage of penetration, short-term trends are generally not good long-term trend factors.
- Short-term trends can be erratic, reflecting differences in consumer behavior, dips and swings in the economy, meteorological differences.
- Air quality strategies normally need to look at a long-term perspective to attain and maintain air quality standards.
- The long-term projection methodology utilized in this report projects how key factors influencing wood use are likely to change and incorporates those changes in the projections. Such key factors include projected growth in households, projected fuel prices, projected level of reliance on oil vs. gas vs. electricity for household heating, and others.

C. REPORT OVERVIEW

The remainder of this report is organized as follows: (a) Section II describes this study's short-term projections of wood fuel use for the three cities: Portland, Seattle, and Spokane; (b) Section III contains long-term trend projections through the year 2000 based on adaption of the Dartmouth model to the three Pacific Northwest cities; and (c) Section IV lists the references and personal contacts that provided the information utilized in this study.

Appendix A contains detailed documentation of the values which were input into the long-term trend model (e.g., household heating requirements, historical and projected fuel prices), and the model changes that were made to apply the projection model to the Pacific Northwest. Appendix B contains a discussion of some of the factors not included in the long-term trend model.

II. ANALYSIS OF SHORT-TERM WOOD FUEL USE TRENDS

The overall objective of this analysis of short-term wood fuel use trends is to quantify recent trends in wood fuel use for the three cities and to project how this may change over the next few years. For purposes of this analysis, "short-term" will refer to trends extended through 1985. Section III estimates long-term trends through the year 2000.

To estimate wood fuel use trends, it would be ideal to have a multi-year data base that quantifies the area-wide total amount of firewood used in homes. This is not available. What is available is a number of direct and indirect indicators, which describe an unknown fraction of the total firewood usage or some indirect measurement of firewood use rates (e.g., sales of wood stoves), or direct measures of the effects of RWC (e.g., air quality impacts from RWC). Some of the parameters do not "cleanly" measure RWC because of interfering influences. All have inherent uncertainties that are difficult to quantify.

Since no single available indicator adequately estimates the magnitude and trends in home wood fuel use, a number of different indicators are reviewed here. Their combined evidence is used to derive a "best estimate" of short-term trends (through 1985). The short-term trend parameters considered are described and evaluated in Section A. Section B describes the findings and conclusions of the short-term trend analyses using the selected indicators with documentary details in Appendix A. Section C summarizes the best quantitative estimate of short-term RWC trends for the three cities: Portland, Seattle, and Spokane.

A. SHORT-TERM TREND PARAMETERS CONSIDERED

In analyzing wood fuel use trends, more weight should be given to parameters that directly measure home firewood use than to parameters that indirectly measure wood use or directly measure its effects, e.g., its air quality impacts. The short-term trend parameters considered in this study are listed below in these three categories:

1. Direct measures of firewood use
    a. Volume of firewood removed from public and private lands under firewood cutting permits
    b. Household surveys of firewood use
2. Indirect measures of RWC
    a. Sales of wood burning appliances
3. Direct measures of RWC effects
    a. Ambient air quality impacts related to RWC

These parameters are described and evaluated in the following subsections. Several criteria were established in advance for the types and amount of data that should be available. First, at least three consecutive years of recent data should be available -- including the three most recent heating seasons. (The six months from October through March were considered a heating season.) Second, no major data gaps should be present. For example, gaps in hourly air quality data might not be significant because the data would eventually be averaged over a heating season for trend analysis, but several missing weeks of data would be significant. Third, the data must be judged reliable.

- Quantifying Firewood Use

One of the two most direct measures of wood fuel use trends would be to quantify, over a series of years, the total amount of firewood used in a given metropolitan area. Two ways to do this are: (1) to monitor all of the significant sources of firewood supply in an area -- e.g., firewood removed from public or private lands under wood cutting permits; or, (2) to determine areawide household firewood use, using survey techniques.

The major sources of firewood for RWC are state and federal forests, privately owned forests which allow firewood removal, and wood processing facility wood waste. Firewood supplies for different metropolitan areas are made up of various mixes of these major supply sources, depending primarily upon land ownership patterns in the region, timber management practices, and market conditions.

Tracking RWC trends by firewood use requires data over a series of years or heating seasons based upon the total amount of firewood used in a given region. This type of information could come from quantitatively monitoring all major sources of firewood supply or from statistical areawide surveys of household firewood consumption. Available information of both types is discussed below.

- Information on Volumes of Firewood Cut for Home Use

People either cut their own wood or buy it from a commercial wood cutter or retailer. Fifty to seventy percent of the respondents to the Task 2B surveys cut their own. The increasing need for permits by individuals and commercial cutters obtaining wood from public or private land provides one of the only data bases on the volumes of firewood used in an area.

Wood cutting permit data typically afford only a rough approximation of the total areawide firewood use. While permits issued to individuals by public and private land managers often specify a limit on the amount of wood that can be taken (typically 5-10 cords/permit), generally no one checks to see how much is actually taken.

Commercial wood cutters usually operate under a stricter permit system or timber sale contract, which does account for the volume of wood taken for purposes of payment. Commercial wood cutters may also subcontract with logging contractors to remove some of their logging residues. Public timber sale contracts give logging contractors first rights to all logging residues or slash. The logging contractor must agree on a plan of disposing of the slash, either by approved burning or other removal, to facilitate reforestation of the site. Contractors are often required to yard unused materials (YUM) to piles near roadways. Such YUM piles become a prime source of firewood and are offered for public consumption under wood cutting permits if the contractor does not otherwise dispose of it.

A growing practice mentioned by a number of forest staff involves truck loads of large logs delivered to groups of homeowners, who may pay over $500 per truck load. This relieves homeowners of the transportation costs and some of the inconvenience of obtaining firewood. Typically only a nominal fee ($.50/cord) for such removal of cull logs or logging residues is charged, but forest staff believe many of these truckloads are not reported in any permit system.

More private landowners, such as timber and pulp/paper companies, are also establishing permit systems to allow the public or commercial cutters to remove logging residues in their forests or unwanted wood from "sort yards" at mill facilities. The permit system also serves to control access to private wood supplies.

The following subsections summarize information about firewood volumes available from woodcutting permits issued for public and/or private lands in the vicinity of Portland, Seattle, and Spokane.

Portland, Oregon

The Mount Hood National Forest is by far the major supplier of firewood to the Portland area. Few state or private forest lands exist near enough to supply Portland with much wood. Much of this land is in second growth timber with little active logging.

Table 2 summarizes the estimated number of wood cutting permits issued to the public in recent years from the Mt. Hood National Forest[2]. Permit totals were converted to firewood volumes using an estimate by Mt. Hood National Forest staff[2a] that an average of 3.5 cords were removed per permit. The staff did not perceive any slackening in the escalation of firewood demand that has been going on for several years. However, they did foresee stronger competition for available logging and wood processing residues from several new private enterprises planned or under construction, including two wood densification plans and several wood-fired electric power producing operations (cogeneration). The demands for raw wood from these facilities could strongly affect the availability, accessibility, and cost of firewood in the Portland area.

Seattle, Washington

Seattle area residents obtain significant amounts of firewood from federal, state and private sources. Table 2 summarizes information on wood cutting permits issued for the Mt. Baker/Snoqualmie National Forest, extensive state forest lands operated by the Dept. of Natural Resources (DNR), and several sort lots and forest lands near Seattle operated by Weyerhaeuser, Inc.

TABLE 2

Estimated Wood Cutting Permits and Firewood Volumes Removed from Selected Federal, State and Private Sources near Portland, Seattle and Spokane

City Permit Source Year	Number of Permits Issued	Volume of Firewood Removed* Board Feet ($x10^6$)	 Cords/Year ($x10^3$)
A. Portland, Oregon			
1. Mount Hood National Forest[2a]			
1976	12,000	-	42
1977	16,000		56
1978	24,000		84
1979	30,000		105
1980	39,000		137
1981	48,000		168
B. Seattle, Washington			
1.a. Mount Baker/Snoqualmie National Forest [2b] (general public)			
7/75-6/76		3.629	7.5
9/76-8/77		4.769	9.5
9/77-8/78		5.518	11.0
9/78-8/79		12.265	24.5
9/79-8/80		16.081	32.2
9/80-8/81		16.157	32.3
1.b. Mount Baker/Snoqualmie National Forest[2b] (4 Districts/commercial cutting)			
1979		.256	0.51
1980		.700	1.40
1981		.710	1.42

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* Volumes provided in board feet were estimates by forest officials. Volumes in cords were calculated using (1) number of permits x average cords taken/permit as estimated by forest staff; or (b) from board feet estimates, using 1 cord = 500 board feet.

TABLE 2 (continued)

City Permit Source Year	Number of Permits Issued	Volume of Firewood Removed*	
		Board Feet $(x10^6)$	Cords/Year $(x10^3)$
2. Washington Department of Natural Resources[2c]			
1978	(3000)		509 (98.2%)**
1979	(3000)		2,170 (99.6%)
1980	2855		835 (99%)
1981	1862		110 (95%)
3. Weyerhaeuser, Inc.[2d]			
1975	760		
1976	920		
1977	1,500	(?)	(?)
1978	3,634		
1979	7,350		
1980	10,500		
1981	19,500		
C. Sookane, Washington			
1. Colville National Forest[2e, 2f]			
1977	3,128	15.7	31,400
1978	4,071	24.7	49,400
1979	4,845	26.7	53,800
1980	9,810	41.6	83,200
1981	9,818	32.1	64,200
2. Idaho Panhandle National Forest[2g]			
1977	1,140	3.08	6,156
1978	1,260	3.40	6,804
1979	2,950	7.96	15,930
1980	3,254	8.78	17,571
1981	3,635	9.81	19,629

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* Volumes provided in board feet were estimates by forest officials. Volumes in cords were calculated using (a) number of permits x average cords taken/permit as estimated by forest staff; or (b) from board feet estimates, using 1 cord = 500 board feet.

**Values in parentheses indicate percentage of total which was taken by commercial cutters.

Mt. Baker/Snoqualmie staff[2b] provided estimates of the firewood removed (million board feet) under wood cutting permits by the general public (estimated at about 3.25 cords/permit in 1980-81) and for commercial wood cutters in four forest districts. Both estimates show a marked leveling in 1980-81 compared to the large increases in recent years. The reason for this apparent leveling of demand was not known. Reduced logging activity due to the depressed homebuilding market reduced normally available volumes of logging residues by over 50%.

Extensive state (DNR) forest lands are near Seattle[2c]. Many are closer than national forest lands and provide easier access (less rugged). DNR's toll free phone receives many request (≃25) each day for firewood information. In response to continuing strong public demand, the State Forester has requested staff suggestions on making more firewood available to the public.

The DNR[2c] wood cutting permits and firewood volumes removed (Table 2, part A2) show an unusual pattern of sharp decline in the last few years. A combination of heavy commercial cutting and the present decline in logging activity may have temporarily depleted wood residues available for firewood. Commercial cutting under DNR timber sale contracts accounted for 95-99+% of the firewood volumes removed from these DNR lands, which supply far more firewood to the Seattle area than the Mt. Baker/Snoqualmie National Forest. However, careful permit records have only been kept for the last two years.

Weyerhaeuser permit totals refer to both cutting on Weyerhaeuser forest lands and in sort yards at Weyerhaeuser wood processing facilities[2d]. A change from 2-4 week permits to daily permits in 1979-80 probably accounts for a significant portion of the increase in the total number of permits issued in recent years and makes this data questionable for trend purposes.

Spokane, Washington

Both the Colville and Idaho Panhandle National Forests are near enough for firewood cutting by Spokane area residents. Table 2 includes wood cutting permit totals and/or forest staff estimates of firewood volume removed from both forests[2e]. The 1981 data from Colville National Forest show a leveling of wood cutting permits and a substantial decrease in firewood volume removed[2f]. However, this may be due to a change in permit procedures, from personally issued by Forest Service staff to self-issuing permits. The change may also have influenced staff estimates of the average number of cords/permit removed. A written survey of 1981 permit holders was the basis for a staff estimate that an average of 5 cords of firewood were taken under self-issued permits.

State forest lands provided Spokane residents with an estimated 4000-5000 cords per year in 1981, according to DNR staff[2h], who said total firewood volumes removed continued to increase approximately 15% per year. Reliable information is hard to obtain because a public wood cutting permit system was not implemented until 1980.

. . . .

Overall, wood cutting permit information has serious limitations as a data base for estimating wood fuel use trends. It is not complete or reliable enough to represent the actual total firewood use in an area. Much firewood can be obtained outside the permit system, and the permit systems themselves do not monitor volumes of firewood actually taken. Trying to inventory the total amount of firewood used in a metropolitan area over successive years to establish a trend would require relatively complete accounting for firewood volumes obtained from all major public and private landholdings, plus an estimate of wood obtained elsewhere -- a formidable task indeed.

Individual permit programs can provide a glimpse of what is happening in a sector of the firewood supply system - especially if reasonably accurate information is available. Analysis of a number of these permit systems in different locations in a region show a pattern of wood fuel use. The data in Table 2 show different patterns in Portland (continuing increase in permits) versus Seattle and Spokane (leveling of permits).

- Wood Cutting Permit Trends

Figure 1 shows plots of selected data intended to represent trends in major portions of the total amount of firewood supplied to households in the three metropolitan areas. Estimated firewood volumes removed under cutting permits (cords/year) during the last 4-6 years are plotted. Dashed trend lines are regression lines of best fit.

All four trend lines show a notable similarity, exhibiting a 5.7-7.9% average annual increase in firewood volume over the last 4-6 years. Trend lines, which are less steeply sloped, begin with smaller initial firewood volumes. Incidentally, this approximate 6-8% annual rate of increase agrees will the model simulation of RWC activity during this same time period (Section III).

For two areas (Seattle, Spokane/Colville National Forest), the most recent (1981-82) firewood volumes are plotted, but are not included in the regression line calculation because they deviated substantially from the trend of the previous few years. In these cases, for the most recent heating season, total wood cutting permits and/or firewood volumes remained about the same as the previous (1980-81) season. In one case (Colville National Forest), estimated firewood volumes removed were down 25% from the previous season. This may have

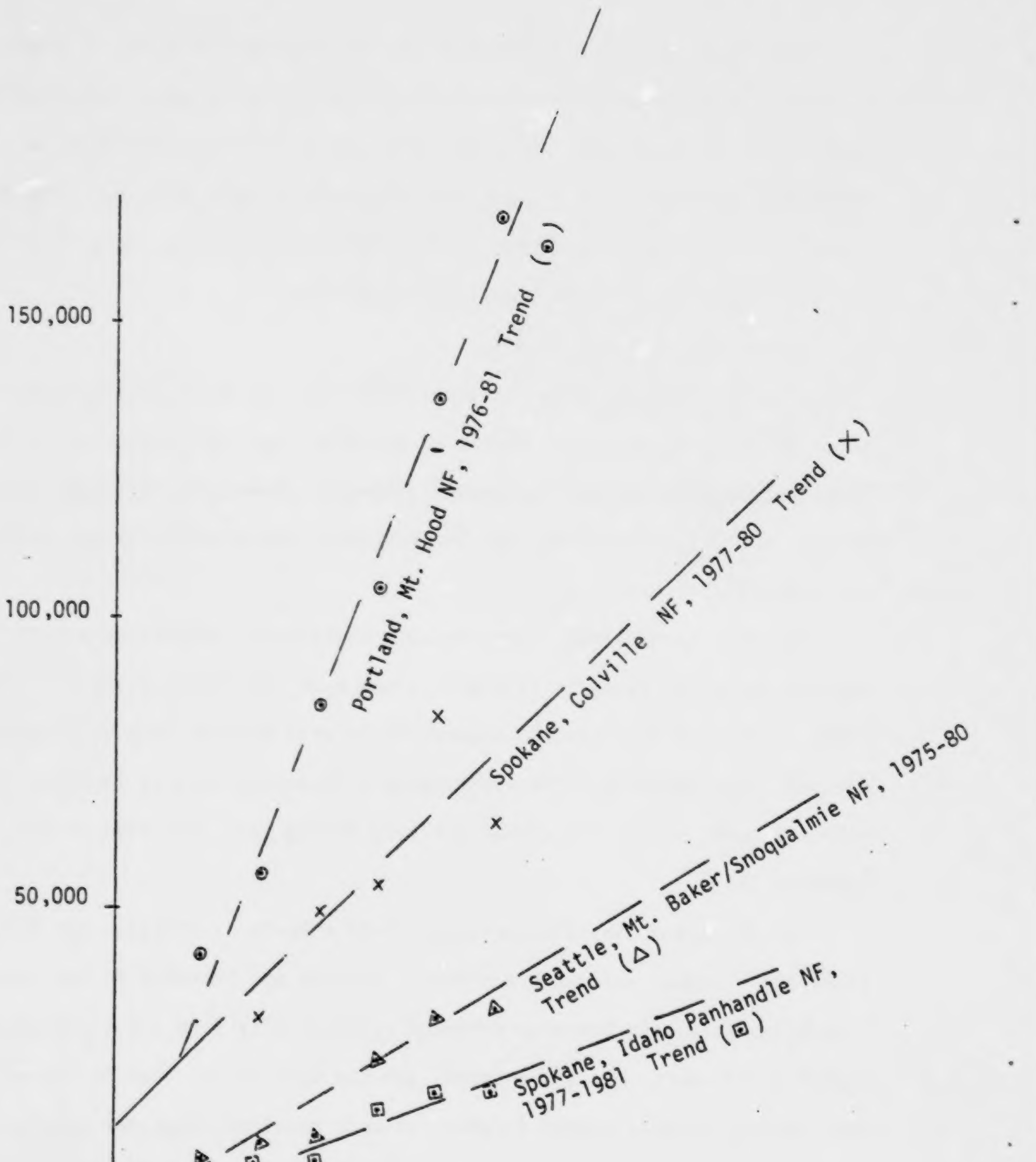


Figure 1. Recent Trends in Firewood Volumes Removed Under Wood Cutting Permits from National Forests Near Portland, Seattle and Spokane.

been due to a change in the methods of estimation used by forest officials.

In any event, the results of these trend analyses indicate that firewood supplied by federal forests near the three cities have been increasing over the last 4-6 years at an annual average rate of about 6-8%, but there are now preliminary indications of a leveling of this trend in at least several of these areas. Aside from the homebuilding/logging slump, which has decreased the amount of logging residues available in most forests, forest officials were not able to identify any decrease in demand for firewood for RWC. Most officials felt demand was strong and would continue to be so.

- Statistical Surveys of Wood Fuel Use by Residence

Survey techniques would appear to be a simpler and more accurate way to track total firewood consumption in a metropolitan area than attempts to inventory firewood cutting permit information, etc., provided such surveys are designed to represent the entire area. Survey data over successive heating seasons would be necessary for trend analysis of areawide wood fuel use.

The Oregon Department of Environmental Quality (DEQ) conducted a telephone survey in 1979 to determine the amount of RWC in three metropolitan areas (Portland-Vancouver, Eugene-Springfield, and Medford-Ashland) during the 1978-79 heating season[1]. This information was used to characterize residential wood space heating as a source of particulate emissions for air quality control planning purposes. Base year (1978) RWC emissions were projected to grow based on either population/household projected growth rates or a more rapid increase using a trend factor based on recent increases in timber harvest volumes. The survey determined the number of cords of firewood used by an "average household". Based on the total number of households in each area, the area total emissions were calculated.

Area total firewood use was not calculated, but is derived from the data collected. For Portland-Vancouver, the average household was estimated to have used 0.89 cords in 1978; 1.73 cords per average wood burning household[1c]. No wood was burned in 45.5% of Portland households[1a]. Thus, Portland-Vancouver's estimated (1978) total of 428,600 households[1a] burned approximately 360,000 cords of firewood in the 1978-79 heating season. This is considerably more than the firewood estimated to have been supplied from the Mt. Hood National Forest (Table 2) in 1978 or 1979.

DEQ surveyed random samples of 400 households in each metropolitan area. The survey was designed to be statistically reliable within ±5% and representative of the entire Portland(OR)/Vancouver(WA) metropolitan area. No other comparable surveys have been done for Portland. Similar data which might support trend analysis of metropolitan firewood consumption is available for other years. Based on this survey, using the two growth factors mentioned above (population/household growth and growth in timber harvest volume wood cutting permits), DEQ projected a growth in total metropolitan firewood consumption of 139% between 1977 and 1987. This implies total metropolitan firewood use of 740,000 cords/year by 1987.

The Task 2B survey of a Portland area residential neighborhood found that 14.2% of its 1981 households used wood as the primary heat source (28% of all households had wood stoves), and 54% of all households burned some wood. The average number of cords burned during the 1981-82 heating season was 2.0. However, these figures are probably not representative of the Portland metropolitan area as a whole because this survey focused on a single residential neighborhood chosen for apparent high levels of residential wood burning.

Neither the Seattle nor Spokane areas had random surveys of areawide wood use. Existing survey data for these two cities[16,18,19] including the Task 2B neighborhood surveys, are discussed in the Appendix A (Sections 2D and 3A(1), respectively). The assumptions made in using this survey data to estimate wood fuel use by residences are explained in these Appendix sections.

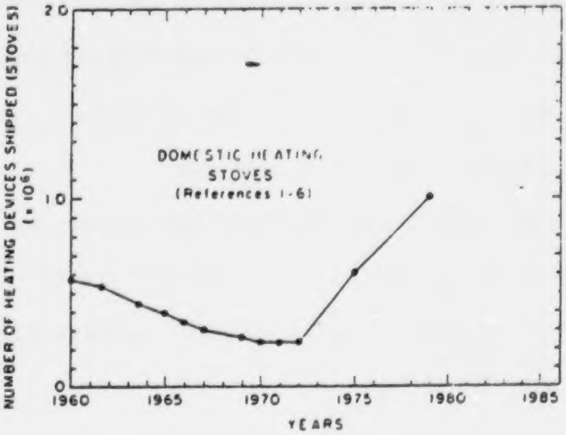
Until some comprehensive system of tracking residential wood combustion over a series of years is implemented, trend analysis of wood fuel use will be limited by data series which represent an unknown fraction of total firewood usage. The most practical methods of quantifying areawide and household wood use involves statistically sound random surveys.

- Indirect Indicators of Wood Fuel Use

Sales of residential wood burning appliances and census data were examined for possible use in estimating wood fuel use trends. Neither trade associations nor manufacturers contacted could or would release actual sales information of use in estimating RWC trends.

Using Bureau of Census data, Cooper plotted the national total number of wood burning stove type devices shipped in this country since 1960[23]. This showed a sharp increase in stoves shipped beginning in 1973 (Figure 2). New data from the U.S. Dept. of Commerce[23] will soon be available to extend this plot beyond 1979. It is possible to obtain only the data for the Pacific Northwest. However, this data was not available within the time and resources of this study. The Oregon and Washington stove sales data represent units sold from those states, which can include a significant amount of out-of-state deliveries. Thus, this data does not represent wood fuel use in the Pacific Northwest so much as sales activity.

Figure 2. Twenty Year Trend in the Number of Wood-burning Stove Type Devices Shipped in the USA.[22]



Moreover, while such data on stove shipments contribute qualitatively to the overall picture of recent sharp increases in RWC activity, they do not provide direct quantitative estimates of wood fuel use, since the amount of wood used per stove is unknown. Accordingly, no analysis of sales data was done to quantitatively estimate short-term RWC trends.

Comparison of 1970 and 1980 census data related to RWC could theorectically shed some light on RWC trends during that ten year period. However, census data provides very little information to estimate wood fuel use or related trends.

The type of fuel used to heat residences is obtained from a census questionnaire, but this information for 1980 will not be published until late 1982 in "Detailed Housing Characteristics". No census information is obtained on secondary (supplmentary) heating equipment of fuel. The Bureau of Census data on the number of wood burning stove type devices shipped in this country was discussed in the previous section. Accordingly, no trend analysis of census data was pursued.

- Direct Indicators of Effect of Wood Fuel Use

Residential wood fuel combustion contributes substantially to ambient air quality problems[24,25]. Of primary concern are RWC contributions of respirable particulate and carbon monoxide (CO) levels. Thus, the following types of air quality monitoring data related to respirable particulates or CO were considered to determine if they could provide a continuous series of data whose trends might be associated with residential wood fuel use trends:

1. Carbon monoxide monitoring data
2. Certain regularly collected air quality monitoring data related to respirable particulate levels, including:

a. Light scattering Coefficient (Bscat) -- The integrating nephelometer, measures the degree to which small particles in the air scatter light, indicated by an hourly average scattering coefficient (Bscat). RWC emissions are largely (90%) small particles.

b. Coefficient of Haze (COH), or Soiling Index -- Air filtered through a tape produces a spot whose darkness is measured by light transmission, indicated by an attenuation coefficient measured every two hours.

c. Benzene soluble particulate extractions -- Benzene extractable non-polar organic materials are associated mainly with combustion process (like RWC), auto exhaust, industrial emissions, and secondary organic aerosols. Gravimetric analysis of extractions gives total "organic" carbon in particulate samples.

d. Total carbon levels and organic carbon to total carbon ratios in particulate (Hi-Vol) samples -- Both these parameters have been shown to rise substantially during winter months, presumably due to combustion of carbonaceous fuels.

- Other Air Quality Data

Some air quality sample analysis techniques, for example chemical mass balance (CMB) and Carbon-14 analyses of fine particulate samples, directly estimate RWC impacts and non-fossil carbon impacts, respectively. The "modern" (non-fossil) carbon impacts can occur from sources besides RWC, such as slash burning, veneer dryer emissions, sanderdust and plant materials (pollen, etc.).

Only the light scattering (Bscat) data was eventually analyzed for trends in this study. The other types of data were considered to be either too subject to interfering sources or had problems with collection efficiency and general accuracy. In some cases, there was simply not enough continuous data to support trend analysis.

While evening peaks in ambient CO levels may correlate well with RWC activity, separation of vehicle contributions to CO levels from RWC contributions makes it impossible to use CO data for trend analysis.

Coefficient of Haze (COH) data suffers from poor collection efficiency of paper tape samplers and general inaccuracy of measurement method. It also reflects impacts from sources other than RWC, such as diesel exhaust, residual oil burning, and fine particulate from industrial emissions.

Benzene soluble extractions of total particulate samples were only available for Portland. DEQ discontinued benzene extractions several years ago. No data is available for the last several heating seasons when the sharpest increase in RWC occurred.

Trend analysis was not performed on total carbon analyses of particulate samples or organic/total carbon ratios for several reasons. Total carbon levels can be influenced by many sources, including auto and truck exhaust, RWC, plant tissues, sawdust, spores, pollen, etc. Even winter carbon levels, typically elevated presumably by combustion heating sources, would at best represent an upper bound for RWC levels. Discontinuance of benzene extraction several years ago in Oregon meant the only data for organic/total carbon ratios available did not cover the most recent heating seasons.

Chemical Mass Balance (CMB) analysis has shown that RWC can be one, if not the major contributor to respirable (<2 microns) and inhalable (<10 microns) particulate levels in Portland and Medford, Oregon. An increasing number of fine particulate monitoring sites are being operated on a regular basis in the Pacific Northwest, but none has accumulated enough continuous data for trend analysis. In the future, periodic measurement of respirable or inhalable particulate mass and CMB analysis of RWC contributions to it, is likely to be the best indicator of RWC trends. However, trend analysis using CMB data would require a large number of periodic samples judged to be representative of winter season air quality.

Task 2A reviews past maximum fine particulate levels observed in Portland, Seattle, and Spokane and several other cities in the Pacific Northwest, including available CMB analyses of RWC levels. These historical samples and CMB analyses provide valuable information on RWC levels at various times and places, but this information is not plentiful or continuous enough for trend analysis.

Carbon-14 analyses of fine particulate samples collected during heating seasons can be one of the most specific analyses of RWC[26,27]. RWC emissions contain entirely "modern" carbon, in contrast to fossil fuels whose greater age has resulted in more C^{14} decay to the isotope C^{12}. Thus, the fraction of a particulate sample contributed by "modern" carbon sources is determinable through measurement of 12C/14C ratios, which can be sensitively and accurately measured. Provided a suitable fine particulate sample is collected, which excludes larger particle size sources such as raw wood fiber or other plant materials, the "modern" carbon component can be attributed to a very limited number of sources, such as RWC or slash burning. Then for major urban areas, other measurements like background site particulate levels and nephelometer data can be used to ascertain whether slash burning smoke intrusions were occurring. On sample days when other vegetative burning influences, like slash or open burning, are known not to have occurred, the vegetative burning impact can be attributed to RWC. However, relatively few carbon-14 analyses have been done to date due to the expense (approximately $1000/sample), and a determination of trends is not possible with the limited available data.

• Trends in Light Scattering (Bscat)

Light scattering (Bscat) measurements can also be influenced by sources of very fine particulate other than RWC - e.g., forest fires, grass field burning, auto traffic, industrial upsets, and secondary aerosol formation. Meteorology also directly influences measured Bscat levels. Several precautions were taken to screen out or eliminate such interferences prior to trend analysis of Bscat data. Nevetheless, the results are presented with the strong caution that they represent trends in ambient air quality impacts which *may* be associated with RWC.

Only Bscat data collected during a "heating season" (here defined as October - March; 6 months) were analyzed to maximize the influence of RWC and eliminate the seasonal effects of such activities as forest fires and grass field burning. Bscat data were normalized for temperature (using heating degree days) and wind speed, to minimize variations due to meteorological factors, as follows:

$$\text{Monthly Average Bscat} \times \frac{\dfrac{\text{Measured Monthly Ave. Wind Speed}}{\text{"Normal" Monthly Ave. Wind Speed}}}{\dfrac{\text{Monthly Total Heating Degree Days}}{\text{"Normal" Monthly Total Degree Days}}} = \text{Monthly Ave. Bscat Normalized for Temperature and Wind Speed}$$

Normalization factors were developed using wind speeds and heating degree days measured at the nearest National Weather Service site. "Normal" values typically representing average values over a period of 30 years or more, were also obtained from National Weather Service records.

Monthly average normalized Bscat data were further averaged to represent a heating season (October - March) and plotted versus time for trend analysis. Visual inspection and regression lines of best fit were used to assess trends

Table 3 summarizes the Bscat data analyzed. Figure 3 shows the resulting plots and (dashed) regression trend lines of best fit.

The sites from which data were selected for analysis were chosen primarily because they provide the longest series of continuous data including the three most recent heating seasons. Site selection was limited. Most sites were surrounded by more commercial or industrial rather than residential land uses. No site in Spokane had the requisite minimum data requirement - i.e., data for the three most recent heating seasons. Portland had sufficient Bscat data for both a downtown site and a rural (background) site.

Figure 3 shows an increase in "heating-season-average" Bscat values at the Seattle and Portland sites of 6-8% per year over the three most recent heating seasons. The average annual increase is almost 8% for the Seattle (Kent) site, and almost 6% at the two Portland area sites. The downtown Portland sites exhibit this rate of increase in normalized Bscat data for the last eight years. The background site values closely track the downtown site values for years where data was available at both.

B. FINDINGS AND CONCLUSIONS

The results suggest that respirable particulate air quality during the heating season has been deteriorating in Portland and Seattle at a very noteworthy rate in recent years. Emission inventory projections and computer modeling results for 1977 vs. 1987 in the Portland Particulate SIP[3] indicate that fine particulate impacts from other major sources are likely to decrease or only increase slightly. Therefore, the increases in Bscat levels are believed attributable to increases in RWC.

TABLE 3

Summary of Short Term Trend Parameters Quantified

Short Term Trend Parameter City	Heating Seasons Trended (No. of Seasons)	Estimated Annual Ave. Rate of Increase (%)
A. Firewood Volume Removed from Nearest National Forest(s)		
1. Seattle, Washington Mt. Baker/Snoqualmie N.F.	1975-80 (5)	7.8-7.9
2. Portland, Oregon Mt. Hood N.F.	1976-81 (6)	6.5
3. Spokane, Washington Colville N.F.	1977-80 (4)	5.7
4. Spokane, Washington Idaho Panhandle N.F.	1977-81 (5)	7.2-7.3
B. Heating Season - Average Light Scattering Coefficient (Bscat)		
1. Seattle, Washington[7] Kent Site	1978-81 (3)	7.9
2. Portland, Oregon[8]		
a. CAMS Site	1978-81 (3)	5.7
b. Carus Site	1978-81 (3)	5.6

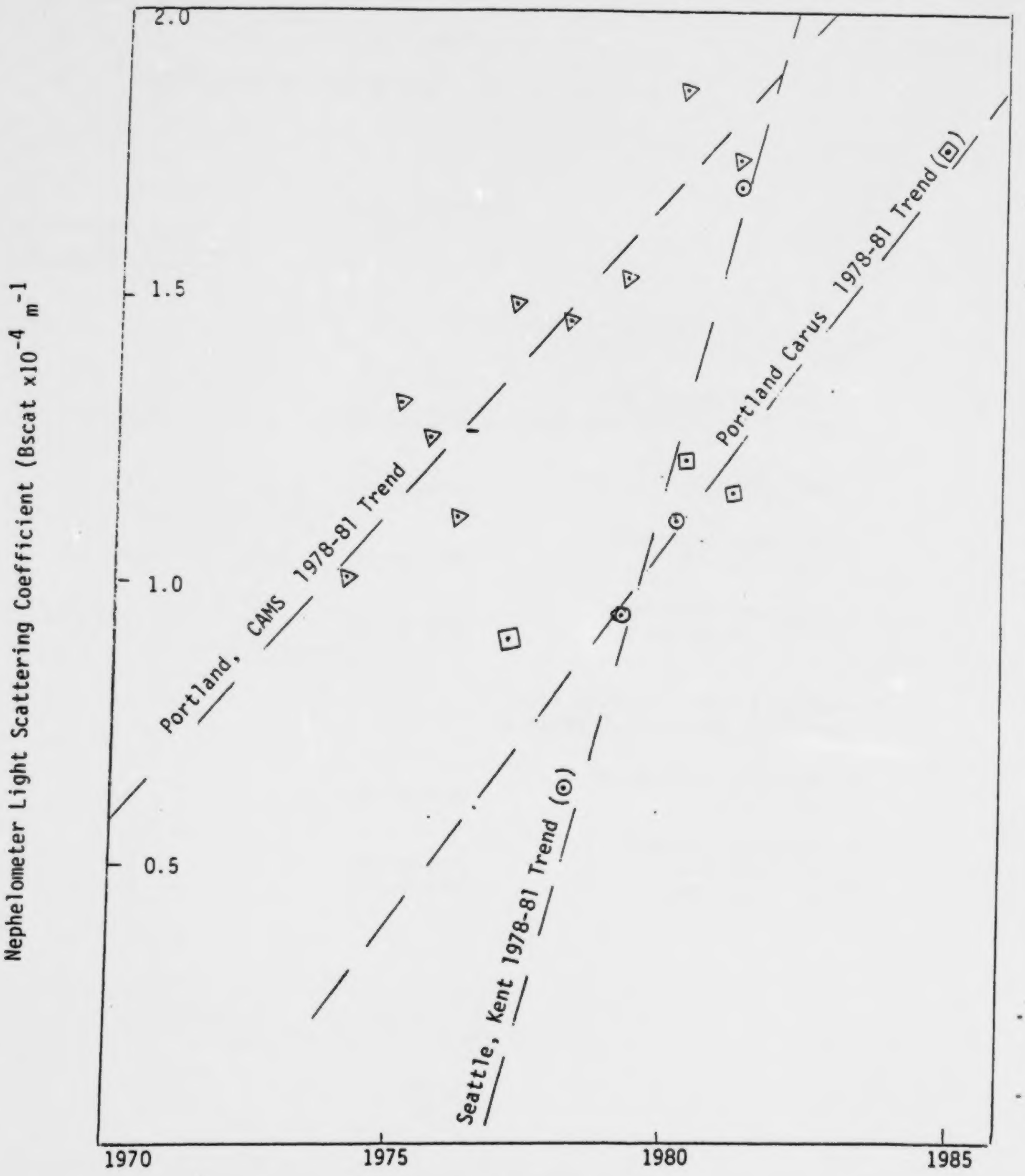


Figure 3 Recent Trends in Normalized Nephelometer (Bscat) Data for Several Portland and Seattle Sites.

At a 6-8% annual rate of change, the average pollution level would double within 9 to 12 years. The recent rate of increase in Bscat is the same as that estimated above for firewood supplied by federal forests. This agreement lends weight to the obvious association between this period of deterioration in respirable particulate (Bscat) air quality and an increase in RWC activity. Further support for this association comes from chemical analysis of fine particulate samples, which shows that RWC is a major contributor to respirable particulate levels.

C. BEST ESTIMATE OF SHORT-TERM WOOD FUEL USE TRENDS

Table 3 indicates that for the two short-term trend parameters for which calculations were made - i.e., firewood removed from nearby federal forests, and heating-season-average Bscat data - the recent annual average rate of increase was 6-8%. Assuming RWC activity has increased in proportion to these related trend factors, our best estimate of the short-term trend in residential wood fuel use is a 6-8% maximum annual average increase. At this annual rate of increase, wood fuel use would increase 34-47% between 1980 and 1985.

Recent indications of a leveling of firewood supplied by several federal forests may signal that the recent trend has begun a significant slowdown. The long-term trend projections in Section III of this report indicate that wood fuel use will grow at different rates in the three cities between 1980 and 2000. Between 1980 and 2000, Portland and Seattle are projected to have annual average growth rates in total wood combustion of 2.0% and 1.0% per year, respectively. Spokane is predicted to have a net increase averaging 0.3% over this twenty year period. However, as discussed in the Findings and

Conclusion of the Long-Term Trends Section, emissions are predicted to increase proportionally more in all areas due to the switch from burning in fireplaces to burning in stoves which have a greater emission rate.

III. ANALYSIS OF LONG-TERM WOOD FUEL USE TRENDS

INTRODUCTION

Long-term projections for use of a resource are generally difficult because factors unforeseen at the time of projection often become important influences later and can radically alter the expected behavior. If, for example, the task of projecting residential wood usage had been undertaken in 1970, it is doubtful that many projections would have foreseen the influence rising prices for oil, natural gas, and electricity have had in motivating households to convert to heating their dwellings with wood. Nevertheless, long-term projections of residential wood usage in the Pacific Northwest are of interest in estimating its severity on future air pollution problems. The analysis described in this section projects residential wood usage through the year 2000 (at 5 year intervals beginning with 1985) for the cities of Portland, Seattle, and Spokane. Portland projections were made on an AQMA basis (roughly equivalent to the Standard Metropolitan Statistical Area), rather than on the city itself, since the baseline information on wood fuel use in 1978 was available for the larger geographical area.

The remainder of this section is organized as follows:

- Methods for Long-Term Wood Fuel Use Projections (Section A)
- Description of Chosen Analytical Approach (Section B)
  - Marshall's economic model
  - Addition of a fireplace wood usage sector to the model
  - Model Calibration
  - Model Sensitivity Analysis
- Findings and Conclusions (Section C)
- Best Estimate of Long-Term Wood Fuel Use Projections (Section D)

Specific details on factors input into the projection model are presented in Appendix A.

A. METHODS FOR LONG-TERM WOOD FUEL USE PROJECTIONS

A wide variety of information sources were examined in order to seek projections within the literature for residential wood usage:

- Library systems at the Bonneville Power Administration and the Western Solar Utilization Network (SUN) were completely reviewed for specific projections of wood usage and general methodologies for projecting energy usage.
- Federal, state and local agencies in Oregon and Washington were contacted such as the Oregon Department of Energy (ODOE), Washington Department of Natural Resources (WDNR), Washington Department of Ecology (WDOE), Oregon Department of Environmental Quality (ODEQ), U.S. Forest Service (USFS), and others. No year 2000 projections were available. Only the ODEQ has short-term wood usage projections which are described in Section II A.
- A search of EPA computerized bibliographies was conducted for subject matter relating to residential wood burning.
- Air Pollution abstracts were searched for wood related articles for the last three years as was the magazine Forest Industries.
- Wood stove and fireplace related trade associations such as the Wood Energy Institute in Portland and the Wood Heating Alliance in Washington, D.C. were contacted.

Information from such sources is referenced in this text where appropriate, and a comprehensive list of references is presented in Section IV.

Major long-term projections of residential wood fuel usage found in the literature included the following:

- Office of Technology Assessment, Energy from Biological Processes, 1980[9]
- U.S.F.S., RPA, An Assessment of the Forest and Rangeland Situation in the U.S., 1980[10]
- Solar Energy Research Institute, Report on Building a Sustainable Energy Future, 1981[11]

Booz, Allen, and Hamilton, Assessment of Proposed Federal Tax Credits for Residential Wood Burning Equipment, 1979[12]

Bradburd, Mead, Schneider, and Art of Williams College, The Use of Wood for Fuel; Historical Series and Projections to the Year 2000, 1979[13]

Bonneville Power Administration (Steve Onisko)[14]

Marshall, Thayer School of Engineering, Dartmouth College, The Dynamics of Residential Wood Energy Usage in New England, 1970 - 2000, 1981[15]

The first five studies above were national in scope and therefore not suitable as a basis for regional projections. Their methodologies are discussed below. Residential wood combustion is a localized phenomena because of high transportation costs, making national trend data of little or no value for specific locations. The last two were regional projections, but the methodology employed by Marshall was clearly superior to that employed by any of the other studies. Only Marshall's report included a review of other projections studies and the assumptions and causal factors behind other researcher's projections. Each of the above projection study methodologies is briefly described below.

1. OTA Projection[9].

The Office of Technology Assessment's (OTA) report, Energy from Biological Processes, makes explicit projection of residential wood fuel use (1.0 quads if "business as usual" and 2.0 quads with "vigorous support and high energy prices"), but there is no firm analytical basis for the projection. These figures are based on Booz, Allen, and Hamilton estimates for 1985 with soft assumptions that growth will occur if low-cost firewood remains available and wood users continue to tolerate wood's lesser convenience than conventional fuels. OTA's soft basis of estimate and the fact that it is a national projection make this method unsuitable for projections in the Pacific Northwest.

2. U.S.F.S. Projections[10]

The U.S.F.S. projects that residential wood fuel use will increase from six million cords annually in 1976 to 26 million cords in the year 2030. Based on these values, a year 2000 estimate of about 15 million cords is derived with linear interpolation and a 12 million cord estimate is derived with exponentialcurve interpolation. Projections are a function of past use trends, population trends, fuel price trends, and fireplace and stove sales trends. However, it is questionable whether it is valid to extrapolate such short-term trends on a long-term basis. The national nature of the projections also make these projections unsuitable as the single basis for projecting Pacific Northwest wood usage.

3. SERI Projections[11]

The Solar Energy Research Center projections are presented in A New Prosperity: Building a Sustainable Future. SERI projects annual residential wood usage peaking in the 1980's in the 1.5 to 2.0 quads range and subsequently dropping to about 1.0 quads per year in the year 2000. SERI's projections are based on consumers' ultimate desire for convenience, improved heating efficiency, other forest land and wood energy use and historical wood use. However, the calculation procedure and its basis are not explained in much detail; and the national focus of the projection cannot be directly applied to the Pacific Northwest.

4. Bradburd, et.al., Projections[13]

Bradburd, et.al. projected residential wood use to the year 2000 in The Use of Wood for Fuel - Historical Series and Projections to the Year 2000 under contract to the US DOE. The model is an optimization model under which an individual is assumed to minimize his cost of space heating requirements, wood price, conventional fuel prices, installation cost, and wood use per household. The model assumes that these factors will basically remain the same through the year 2000. Since these factors can be expected to change significantly over the next 20 years, the model appears to have limited validity for long-term projections.

5. Booz, Allen, and Hamilton, Inc. Projections[12]

Booz, Allen, and Hamilton, Inc. projected future wood usage in Assessment of Proposed Federal Tax Credits for Residential Wood Burning Equipment produced under DOE contract. Oil displacement by wood usage is predicted and then converted to estimates of wood usage. Wood usage of 0.8 quads is projected for 1985 (no 2000 projections) with 1.0 quads consumption rate projected with 30% tax credit for purchase of wood heating equipment. The projections for future consumption without a tax credit are based on historical wood burning equipment sales and manufacturer's projections of sales. Extrapolation of such short-term trend factors does not appear to be a valid method for 20 year projections when the economic factors motivating increased wood usage in recent years can so easily change over a 20 year period.

6. BPA Projection[14]

In 1980, the Bonneville Power Administration (BPA) projected[14] that by the year 2000 RWC could offset 4.6% of the electrical space heating in the Pacific Northwest, saving 3,720 million kwh of electricity. This assumed that 40% of the estimated 1,943,700 electrically heated homes in the year 2000 would use wood as a primary or secondary heat source. This represents an increase in wood fuel use of about 635,000 cords/year, between 1980 and 2000, throughout the Pacific Northwest. While interesting, these projections dealt only with electrically heated households (estimated to account for 60% of all households by 2000), so the approach was not comprehensive enough for this study.

7. Marshall's Projections[15]

Marshall projected residential wood usage in a thesis completed June, 1981, entitled The Dynamics of Residential Wood Energy Use in New England 1970 - 2000. Review of the work by Marshall indicated that it had the most sophisticated and best documented methodology for projecting wood usage. It included full documentation and listing of the computer model used, as well as an explanation of which variables would need to be altered to apply the model to other regions of the U.S. This model takes into account the most variables expected to influence residential wood combustion levels of any of the projections reviewed.

Marshall's work was funded by the U.S. Forest Service Forest Product's Laboratory in Madison, Wisconsin and the Forest Economics subsection charged with making national projections for residential wood burning. Mr. Ken Scog, U.S.F.S project monitor for Marshall's work, confirmed that the Marshall report was the state-of-the-art methodology for projecting residential wood usage within a specific region. He felt that applying the Marshall model to the Pacific Northwest should be a most reasonable basis for projecting future residential wood usage in the Pacific Northwest. Accordingly, Marshall's economic model was selected as the methodology used to estimate long-term fuel use for the Portland, Seattle and Spokane areas.

B. DESCRIPTION OF SELECTED ANALYTICAL APPROACH

1. Description of Marshall's Model

The driving force behind the spectacular increase in residential wood combustion throughout the U.S. in the last decade has been the spiralling cost of home heating with conventional fuels such as oil, gas, and electricity. For example, Seattle distillate oil prices increased from 21 cents per gallon in 1970 to $1.08 per gallon in 1980. The price for 100 therms of natural gas in Seattle increased from $15.60 to $61.43 during that time period. The increase in annual home heating costs from $100 to $150 to costs in the vicinity of $500 to $1000 per year caused many homeowners to seek less expensive ways of home heating. Many chose to install wood burning systems for home heating.

Marshall's model for projecting wood usage is an economic model in which percentages of the population are assumed to install wood heating systems based on cost differentials between heating with wood and heating with conventional fuels. A weighted conventional fuel heating cost (in proportion to usage of oil, gas and electricity) is compared with the cost of heating with wood. The magnitude of the potential fuel cost savings drives the installation of new wood burning devices and determines the assumed rate of capacity utilization (percent of total possible usage) of wood heating system.

Important non-economic factors incorporated in the model include 1) the effect that self-cut wood has on people's perception of the wood cost; and 2) the effect that inconvenience has on people's perception of wood heating costs. The model also incorporates relationships that can be expected to change over time, such as 1) the effect that market penetration will have on increasing wood heating system installation costs; and 2) market penetration effects on increasing perceived inconvenience costs of wood heating. These effects are consistent with common sense since first installers will be people with easiest installations (i.e., existing fireplaces) and least inconvenience costs (easy access to wood, etc.).

Perhaps the most important feature of this model is the use of best available information on the cost of heating with wood versus alternative heating fuels (oil, gas, electricity) to simulate how these cost factors will interact to influence future levels of RWC. All of the model's assumed relationships are spelled out in understandable form and well documented enabling future researchers to build on a solid framework rather than having to start from scratch. New changes can be easily incorporated into the model. Marshall specifies the assumptions incorporated in the model which are listed verbatim in Figure 4.

The model also includes a coal module and a pollution sector (where particulate emission problems can be assumed to lead to regulations, which increase the cost of new wood burning units). Both the coal and pollution modules are set to have neutral effect in Marshall's New England projections and our Pacific Northwest projections. The structure to incorporate these effects has been included in the model, but does not affect the results. Thus, researchers can easily experiment with the potential influence of coal usage or pollution regulation if they so desire.

2. Addition of a Fireplace Wood Usage Sector

Although Marshall's work represents the best methodology found in the literature for projecting residential wood usage, it is deficient in that it

Figure 4.15 Basic Assumptions In Marshall's Wood Use Projection Model

- Wood-heating equipment may be installed in new housing units or retrofitted into existing housing.
- Decisions to invest in wood-burning equipment are made on the basis of marginal costs and benefits.
- The decision to install wood-heating equipment in new housing is a function of fuel savings and non-economic factors.
- The decision to retrofit wood-heating equipment into existing housing is a function of economic payback period and non-economic factors.
- The economic payback period is equal to installation cost divided by annual fuel savings.
- Installation cost reflects the amount of the housing with installed capacity, the fraction of the household's heating needs met by the wood-heating capacity, and the level of pollution abatement.
- The least expensive installations will in general be performed first. Therefore, as the market is penetrated, installation cost increases.
- Early adopters with their own wood supply will have a lower perceived wood-heating cost than later adopters who must purchase all of their wood.
- Non-economic factors incorporated into the model are convenience and pollution.
- Consumers for whom convenience is not a major issue will in general install wood-burning equipment first. Therefore, as the market is penetrated, inconvenience cost increases.
- Fuel prices, the size of the housing stock, heating efficiencies, and household heating requirements are all exogenous inputs to WOODSTOV-2.
- Stove usage may displace a greater quantity of fuel than if the same quantity of heat were provided by a central furnace.

does not include projections for use of wood in fireplaces. This is because Marshall and the sponsor, the USFS, were originally interested in the use of wood for heating purposes. Fireplace heating efficiency is considered to be nominal ranging from negative values up to 10 or 15%. Marshall and the USFS regarded fireplace use as primarily for aesthetic purposes and of lesser importance compared to wood usage in stoves and furnaces. However, one of the early wood usage surveys conducted for the Portland area, the Talbot Wong study[1] showed that well over half of the wood burned in the Portland metropolitan area in the 1977-78 heating season was burned in fireplaces. Given the magnitude of fireplace wood usage compared to wood usage in stoves in the early years of the wood heating expansion, the addition of a fireplace wood usage sector was a decided improvement to the model.

Fireplace usage (as compared to stove, insert, or furnace usage) can be expected to drop over time for a variety of reasons:

- Fireplaces are very inefficient (from negative to about 10% efficiency) when compared to wood stoves (40 to 60% efficient). This explains why many households are willing to substitute stove usage by installing them in existing fireplaces.
- As fireplace installations are converted to stove installations, wood usage in fireplace drops.
- Increasing wood prices can be expected to reduce fireplace wood usage. Aesthetic wood burning does not have the economic payback achievable with stove wood burning.

Thus, the fireplace sector should utilize factors or relationships that reduce fireplace wood usage over time. A review of several surveys, such as the New England Fuel Wood Survey and Oregon wood heating surveys, confirmed that this expected behavior did in fact occur in the last few years of the 1970 to 1980 time period. These survey findings are explained in detail in Appendix A, Section 1c.

Based on a review of alternate methods by which the expected fireplace wood usage reduction could be "driven" (also explained in Appendix A), a methodology was selected by which future fireplace usage drops as real wood price increases in future years.

3. Limitations of Marshall's Model

Marshall's model does not directly take into account three major factors that can influence wood burning levels. These factors are: the availability of wood resources; the effect of various conservation efforts; and the effects of various governmental policies to either encourage or discourage residential wood combustion. All three factors will in turn influence other variables which are included in the model, such as wood fuel price and household heating requirements. Further discussion of these three factors is included in Appendix B.

4. Calibration of the Model

a. Portland Model Calibration

A review of wood usage survey data for the three metropolitan areas showed that no reliable estimates to confirm the model accuracy (calibrate the model) were available for either the Spokane or Seattle areas. Survey data for both fireplaces and stoves was available for the Portland area from the Talbot Wong survey[1] for the 1977-78 heating season. The Portland data was used as the primary basis for model calibration together with 1970 census data for primary heating with wood for Oregon as a whole and with DEQ/Talbot-Wong estimations for 1980 wood usage in the Portland metropolitan area. Additionally, some estimated stove sales data was available for the state of Oregon from the Wood Energy Association in Portland.

The available data for use in model calibration was as follows:

• 1977 Portland metropolitan area fireplace wood usage	209,000	cords/yr
• 1977 Portland metropolitan area stove wood usage	81,000	
• 1980 Portland metropolitan area stove wood usage	144,000	
• 1980 Portland metropolitan area fireplace wood usage	215,000	
• 1978 Oregon stove sales	25,000	stoves/yr
• 1978 Portland area stoves sales inferred to be	12,500	
• 1979 Oregon stove sales	33,000	
• 1979 Portland area stove sales inferred to be	16,500	
• 1980 Oregon stove sales	30,000	
• 1980 Portland area stove sales inferred to be	15,000	

In the calibration work, wood usage was considered to have greatest importance. Sales data served as a secondary reference. Also, since DEQ's fireplace wood usage projections did not project a drop in fireplace wood usage, the DEQ estimate of 1980 fireplace wood usage was not utilized in calibration work (with increasing wood prices, use of fireplaces should have decreased, not increased, since it is largely aesthetic).

A detailed explanation of model inputs and changes is presented in Appendix A. Figure 5 shows the model's portrayal of wood stove and fireplace usage from 1970 to 1982 and the correlation with available data on actual wood usage.

A good bit of known historical behavior is predicted with wood usage in stoves accelerating in 1976. The 1977 stove wood usage is plotted at 80,000 cords, which is close to the estimate of 81,000 cords/year in Figure 6. The 1980 stove wood usage is shown at 150,000 cords/year, close to the 1980 estimate of 144,000 cords/year. Wood usage in fireplaces is shown to begin to drop in 1979.

Stove sales, together with wood usage in stoves is portrayed in Figure 6

FIGURE 5

Portland Metropolitan Area Total Wood Usage, Fireplace Wood Usage and Stove Wood Usage Using Marshalls's Model

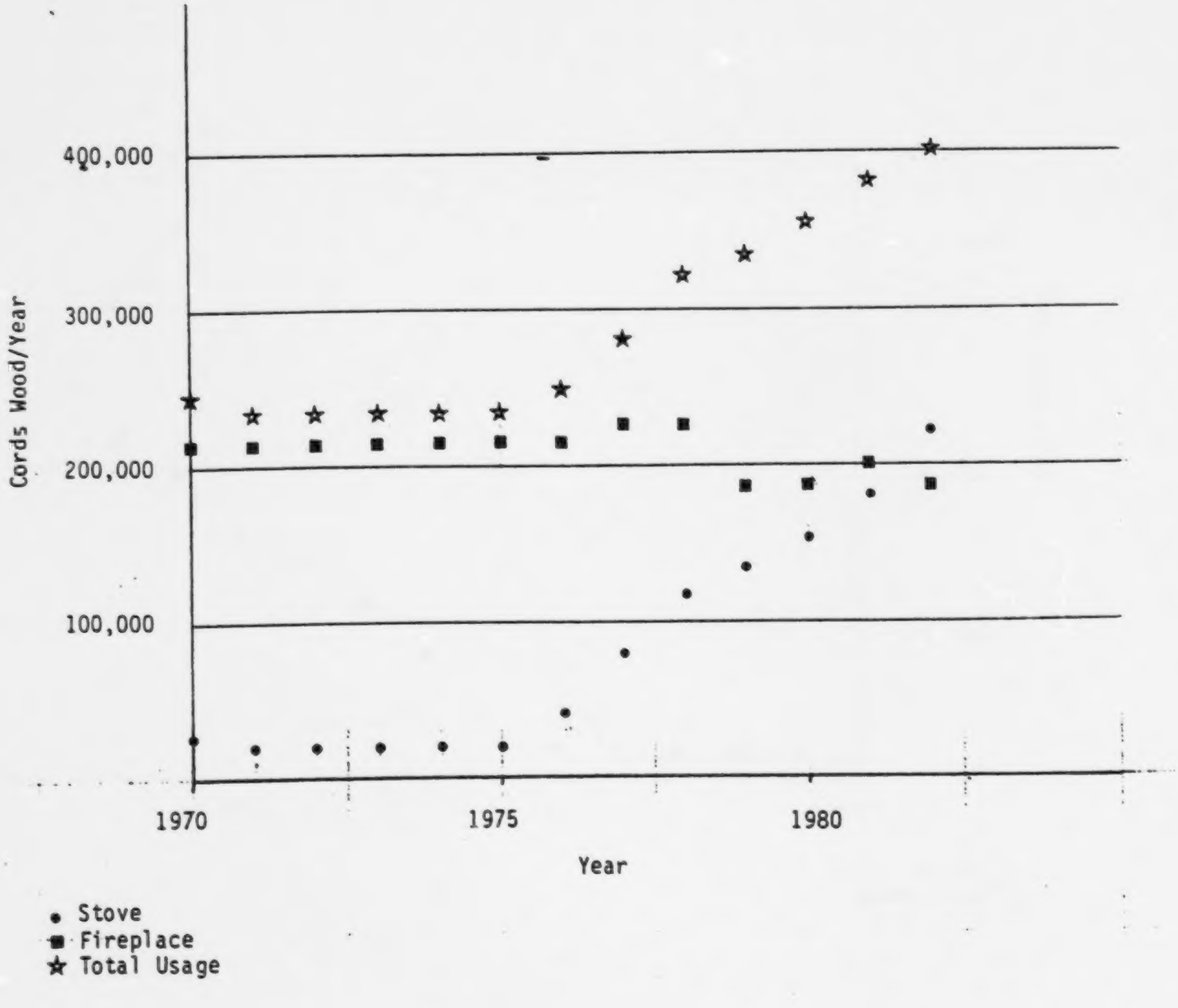
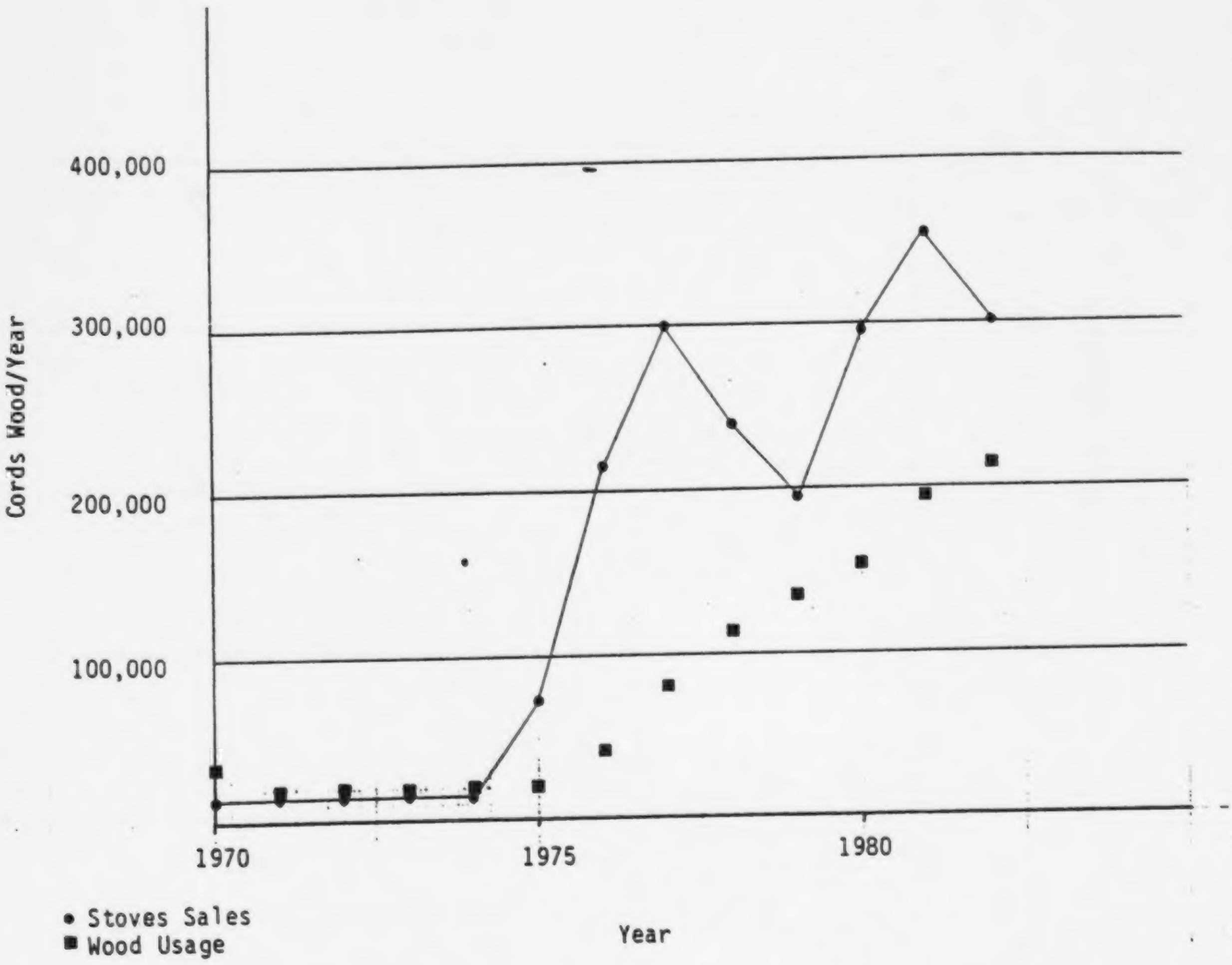


FIGURE 6

Portland Metropolitan Area Stove Sales
and
Stove Wood Usage - 1970 - 1982
(Cords)



for years 1970 through 1982. Sales portrayed by the model are in the 13,000 to 20,000 per year range for the years 1976 through 1980 which is close to the available estimates for the Portland metropolitan area in years 1978 through 1980. The model portrays a drop in stove sales the last part of the 1970's, which is close to the year when sales actually did drop (1980). The fact that stove sales do not exactly follow the estimated sales data is not of concern since 1) Marshall states that the model should not be calibrated on sales, but rather on wood usage; 2) the sales data is for Oregon only, rather than Portland; and 3) the Wood Heating Alliance acknowledges that their stove sales data has significant uncertainty (an estimate was made of how much of total Oregon stove sales to all states were sales returning in Oregon installations).

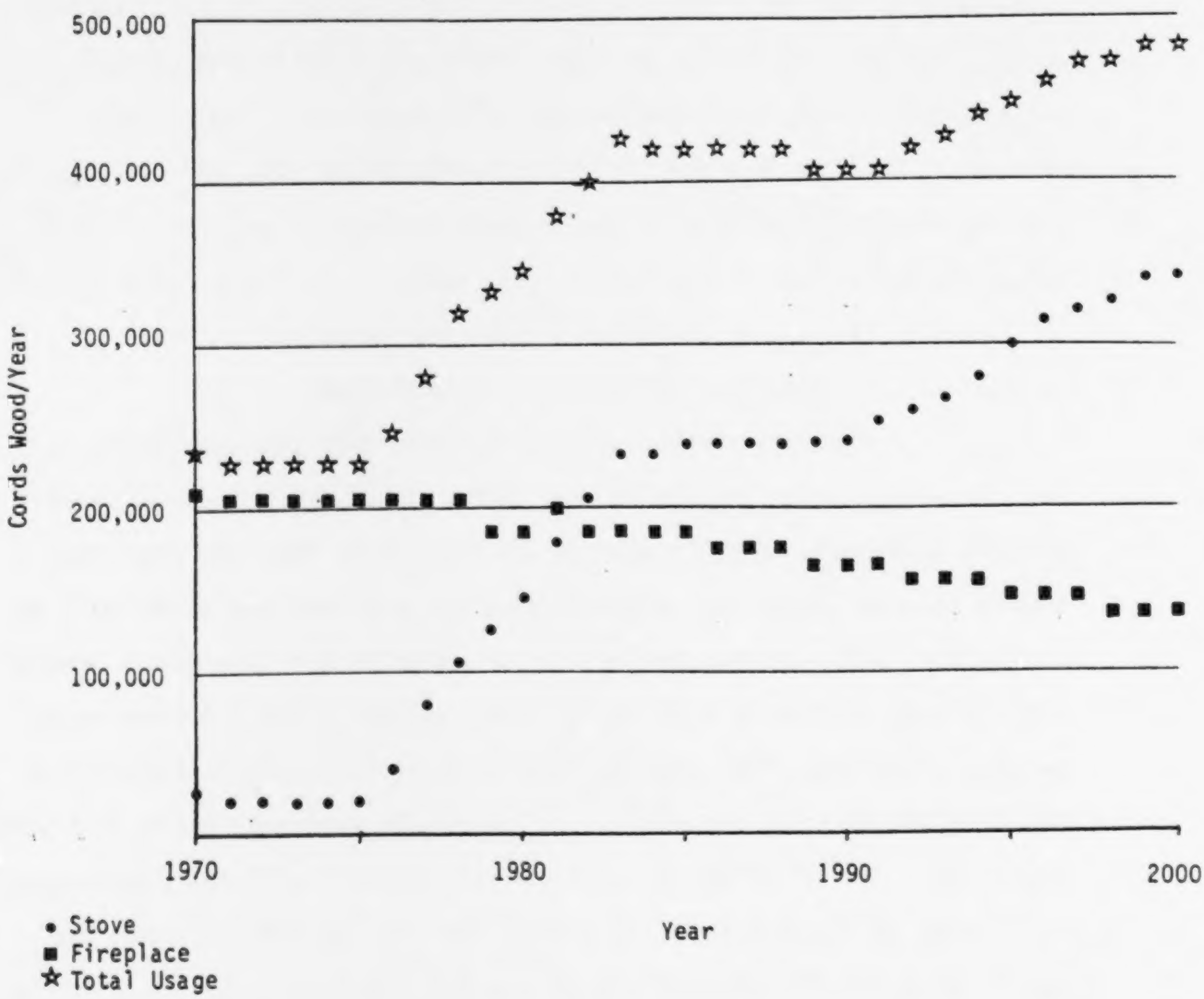
Based on this close simulation of historical behavior, the Portland metropolitan area model was considered to be calibrated.

Figure 7 shows the Portland metropolitan area BASE CASE projections for residential wood usage through the year 2000 in stoves and fireplaces as well as total wood usage. This is based on the most likely fuel cost escalation factors and a 2% annual real price increase for cord/wood used by Marshall for New England. Usage of wood in stoves is projected to more than double between 1980 and 2000, increasing from 150,000 cords per year to about 320,000 cords per year in the year 2000. However, wood usage in fireplaces is projected to drop from 200,000 cords per year in 1981 to 140,000 cords/year during that same time period. The net effect of these opposite trends is that total wood usage is projected to increase about 41% between 1980 and 2000 (340,000 cords per year to about 480,000 cords per year in the year 2000).

The short-term trend analysis from recent years showed that residential

FIGURE 7

Base Case Projection for the Portland Metropolitan Area
for
Stove and Furnace, Fireplace, and Total Wood Usage
(1970 to 2000)



wood usage in Portland has been increasing at about 6.5% per year. The model projections coincide almost exactly with this 6.5% growth rate. The three numbers on Figure 7 at years 1981, 1982, and 1983 show expected total wood usage would be with a 6.5% growth rate from a 1980 base of 340,000 cords (373,000 short-term trend vs 380,000 modeled; 397,000 vs. 400,000 modeled; and 423,000 vs. 420,000 modeled).

Short-term extrapolations inevitably diverge from true behavior in any systems with the passage of time, and the model projects a leveling in total wood consumption beginning in the mid-1980's. For the period between 1984 and 1988, the model projects a 0% growth rate in residential wood consumption, resuming a moderate growth rate averaging 1.6% per year from 1990 through the year 2000.

Between 1980 and 2000, total wood usage is projected to increase only by about 41%, from 340,000 cords/yr to about 480,000 cords/yr. However, the air quality implications are more significant since stove wood burning is expected to increase by about 125% (340,000 versus 150,000).

Most stoves are the airtight kind, which have more emissions per cord than fireplaces. If DEQ-estimated emission factors were to remain constant through the year 2000, total emissions from wood burning would increase by 72% as shown in Table 6. This is discussed in more detail in the Portland area conclusion section.

TABLE 4

Projected Range of Year 2000 Wood Usage by Appliance
for the Portland Metropolitan Area

Appliance	Range of Projected Wood Usage	Best Estimate
Stove/Furnace	280,000 to 400,000	340,000
Fireplaces	100,000 to 150,000	140,000
Total Wood Usage	380,000 to 550,000	480,000

Figure 8 shows the projection for wood usage in stoves and furnaces for New England as projected by Marshall. The general pattern projected shows the same acceleration of use in the late 1970's, the same "slowdown" in the rate of increase in the 1980's, and a similar reacceleration in the 1990's. Trends in the 1970's in wood usage in both New England and the Pacific Northwest were very similar. This can be ascertained by comparing the 1970 to 1980 portions of the curves in Figures 7 and 8. The portions were calibrated on historical use data. Thus, it is not too surprising that future year projections are comparable in terms of the general shape of the curve.

b. Seattle and Spokane Model Calibrations

Similar calibrations of the model for use in Seattle and Spokane are described in Appendix A (Sections 2d and 3d). The Base Case 1970-2000 projections which form the basis for the best estimates of long-term trends in wood usage (Section C) are also described in these appendix sections. Before describing the Base Case best estimates, a preliminary sensitivity analysis of the model is described in the following section -- again using Portland data for illustration.

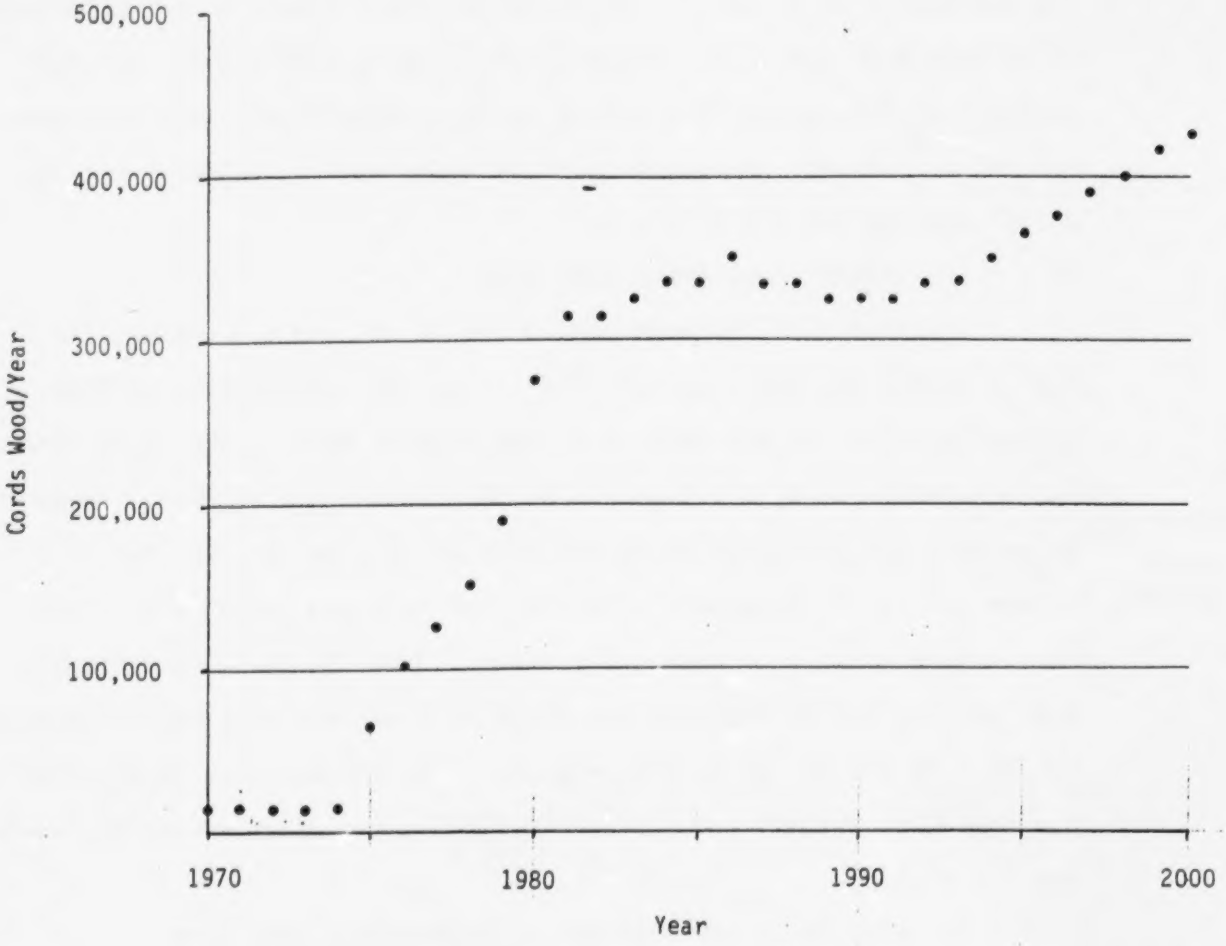
4. Sensitivity Analysis

Some sensitivity analysis was conducted for the Portland version of the model in order to determine whether the model responds to changes in future year conditions in a manner consistent with "common sense" expected results.

The primary factor increasing residential wood usage in this economic model is the potential fuel cost savings, which is the difference between the cost of heating with wood and the average cost of heating with conventional fuels. Sensitivity analysis was performed to test the effect on projections of

FIGURE 8

New England Projection
for
Wood Usage in Stoves and Furnaces
1970 to 2000



either increasing or decreasing the cost of wood fuel relative to conventional heating fuels. The projected real price growth rate for wood between 1980 and 2000 was 2% in the New England model base case. A similar rate was assumed in the Portland base case. In the sensitivity runs described below, the effect on projections was evaluated for two cases: 1) a constant real wood price (in 1980 dollars) between 1980 and 2000 instead of the 2% growth in real price used in the base case; and 2) wood prices increasing at 5% (real growth) per year. In both cases the real price escalation rates of conventional fuels (oil, gas, and electricity) were held constant and the differences in projected wood fuel use between 1980 and 2000 were noted.

a. Constant Wood Prices 1980 - 2000

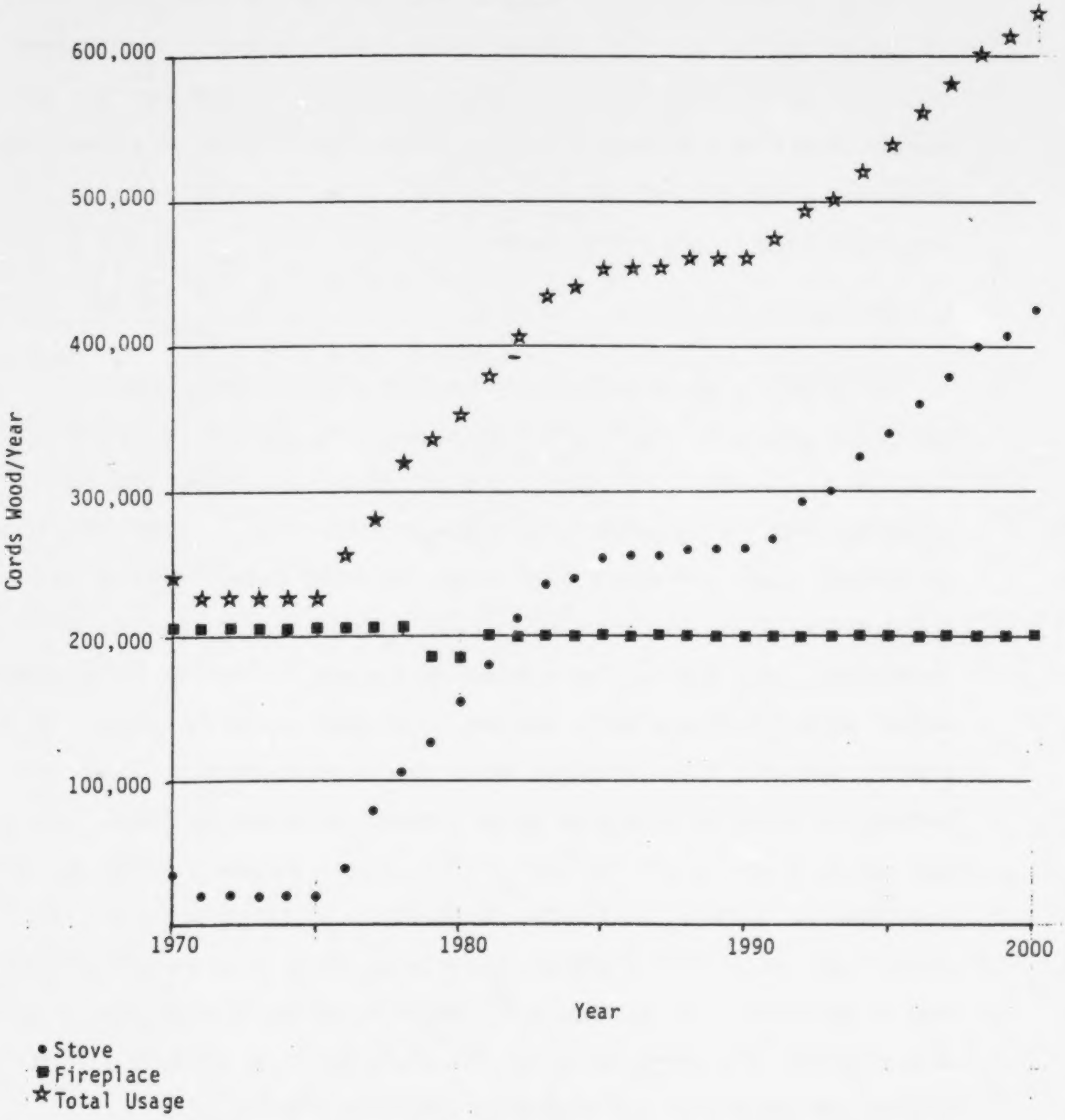
Figure 9 shows the model projections for the Portland metropolitan area if wood prices remain constant (in 1980 dollars) between 1980 and 2000. With no escalation in real wood prices, the usage of wood for heating in stoves and furnaces increases to a level of 430,000 cords per year in 2000 as compared to the base case projection of 340,000 cords per year for the year 2000 (Figure 8) or a 26% increase in usage above the base case projections. Thus stove wood usage would be projected to increase from 150,000 to 430,000 cords/year (187%) versus the base case projection of an increase from 150,000 cords to 340,000 cords (127%). As would be expected, fireplace wood usage is projected to remain about constant under the wood price/fireplace usage assumptions input into the model.

b. Five Percent Per Year Wood Price Escalation 1980 - 2000

On the other side of the scale, if real wood prices are projected to increase at 5% per year, then wood usage is projected to peak in the mid 1980's

FIGURE 9

Portland Metropolitan Area Wood Use Projections
with
Constant Wood Price from 1980 - 2000
(1970 - 2000)



and drop in the following years. This projection is shown in Figure 10.

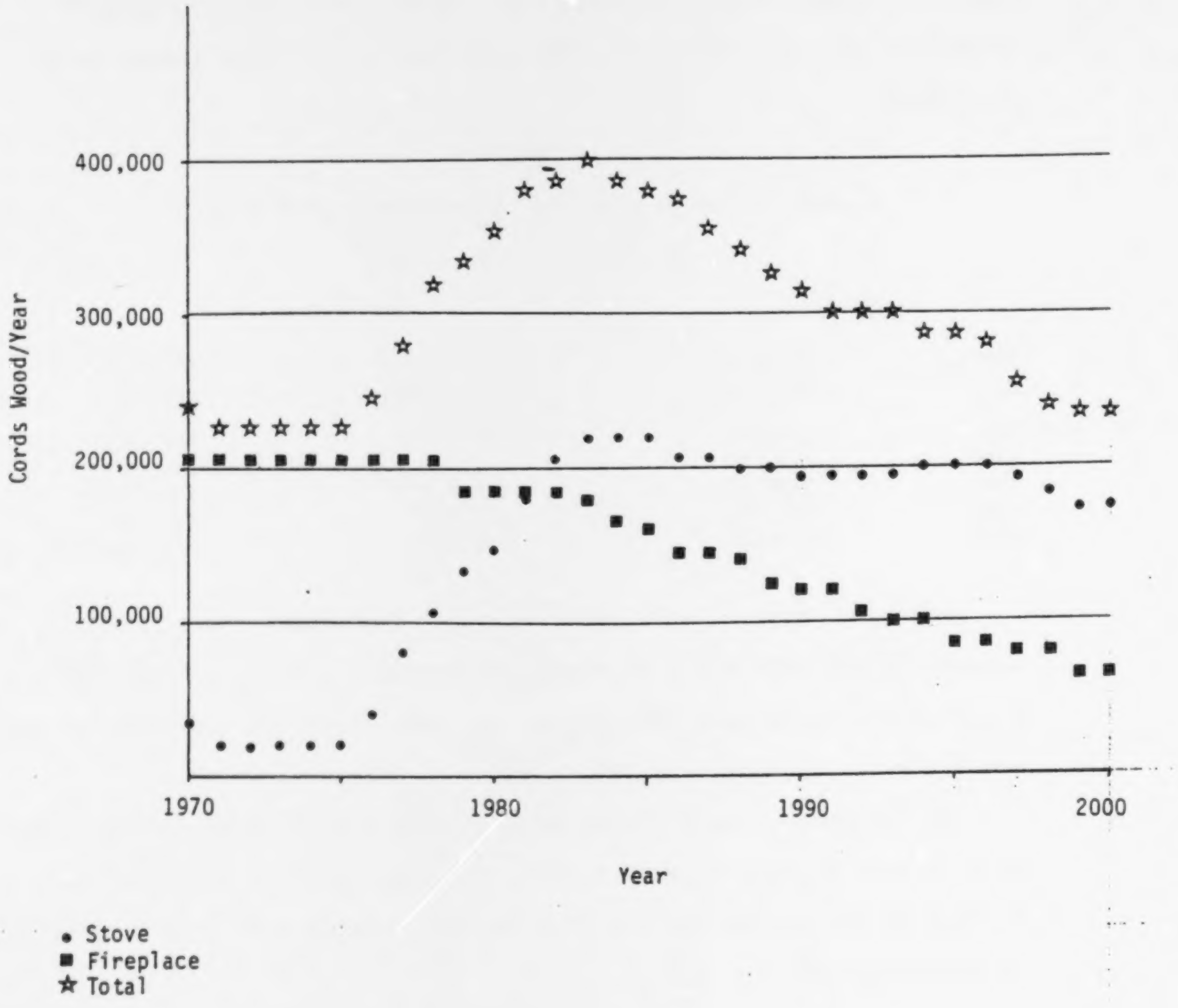
Based on these sensitivity analysis runs and others not discussed here, it appears that the model does respond in a reasonable manner to input changes that alter the potential savings achieved by converting to wood heating. For example, with a 0% wood price escalation between 1980 and 2000, total year 2000 wood usage of 630,000 cords would be projected. The 5% escalation factor results in usage of only 240,000 cords.

C. FINDINGS AND CONCLUSIONS

This analysis adopted and applied the state-of-the-art model for projecting wood usage. Historical wood usage between 1970 and 1980 is well predicted by the model. The model's predictions for 1981 through 1983 are consistent with the short-term trend findings from Section II. This application of the model added a fireplace usage sector, which was deemed necessary because fireplace wood usage was over twice as great as wood usage in stoves in 1977 in Portland. Many important non-economic factors are incorporated in the model, and all assumptions are clearly described. The model is fully documented in a manner that will allow interested researchers to input alternate assumptions, factors, and price projections as better information becomes available. This work was achievable within the scope of this contract because of Norman Marshall's development of the model and complete documentation of its structure and input assumptions. As in all projections, the accuracy of the final results is dependent on the accuracy of the input data. Major deviations in future fuel prices or availability from predicted values will likely result in substantial shifts in levels of residential wood combustion from those predicted.

FIGURE 10

Portland Metropolitan Area Wood Use Projections
with
5% Per Year Real Wood Price Escalation
From 1980 - 2000



1. Portland Metropolitan Area

The authors' best estimates of year 2000 total wood usage is about 480,000 cords/year. This represents the projections using the Bonneville Power Administration's most likely price escalation rates for oil, gas, and electricity and a 2% real price escalation factor for wood. Table 4 presents year 2000 ranges of projected wood usage. Table 5 shows the best estimate projections for years 1985, 1990, 1995, and 2000 for all three categories of wood usage.

TABLE 5

Best Estimate Projection of Residential Wood Usage
in
Portland for 1985 - 2000

Year	Stove/Furnace Wood Usage	Fireplace Wood Usage	Total Wood Usage
1980	150,000	190,000	340,000
1985	240,000	190,000	430,000
1990	240,000	170,000	410,000
1995	300,000	150,000	450,000
2000	340,000	140,000	480,000

Total wood usage is projected to increase at an annual rate of 6.5% between 1980 and 1983 with a 0% growth rate projected between 1984 and 1988 and a 1.6% growth rate between 1990 and the year 2000. A 41% increase in total wood consumption is projected from 1980 to 2000.

The net growth rates projected above indicate a shift in the common devices in which wood is projected to be burned. Stove wood usage is projected to increase by 127% between 1980 and 2000, whereas fireplace wood usage is projected to decrease by 26%.

Even though total wood usage is projected to increase by only 41% between 1980 and the year 2000, emissions can be expected to increase more dramatically. Wood burning in stoves produces more emissions per cord than fireplaces do and is projected to increase by 127% in the 1980 to 2000 period. Table 6 shows how emissions from the various wood burning categories can be expected to change, using current DEQ emission factors for stoves and fireplaces. Even though the projected increase in total wood burning in only 41%, the projected particulate emissions increase (if emission factors were to remain constant) is 71%. This clearly points out the importance and need for lower-emitting residential wood burning stoves and fireplaces.

TABLE 6

Projected Change in Emissions
From
Portland Residential Wood Burning

Year	Stoves		Fireplaces		Total	
	Wood Burned (Cd/yr)	TSP Emissions* (T/yr)	Wood Burned (Cd/yr)	TSP Emissions* (T/yr)	Wood Burned (Cd/yr)	TSP Emissions* (T/yr)
1980	150,000	5,925	190,000	3,325	340,000	9,250
1985	240,000	9,480	190,000	3,325	430,000	12,805
1990	240,000	9,480	170,000	2,975	410,000	12,455
1995	300,000	11,850	150,000	2,625	450,000	14,475
2000	340,000	13,430	140,000	2,450	480,000	15,880

* Assuming 1.75 tons wood/cord; fireplace and stove TSP emission factors of 20 and 45 lb/ton[20], respectively. Emission factors are assumed to remain constant. Improvements in stove efficiencies will reduce emission rates.

2. City of Seattle

These authors' best estimates of year 2000 total wood usage in Seattle city is about 185,000 cords per year. This represents the projections using BPA's most likely price escalation rates for oil, gas, and electricity, and a 2% real price escalation factor for wood. Table 7 presents year 2000 ranges of projected wood usage and best estimates for stoves/furnaces, fireplaces, and total wood usage. Table 8 shows the best estimate projections for years 1985, 1990, 1995, and 2000 for all three categories of wood usage.

TABLE 7

Projected Range of Year 2000 Wood Usage by Appliance
For the City of Seattle
(cords/year)

Appliance	Best Estimate
Stoves/Furnaces	85,000
Fireplaces	100,000
Total Wood Usage	185,000

TABLE 8

Best Estimate Projection of Residential Wood Usage 1985 - 2000 in Seattle
(cords/year)

Year	Stove/Furnace Wood Usage	Fireplace Wood Usage	Total Wood Usage
1980	45,000	110,000	155,000
1985	85,000	100,000	185,000
1990	85,000	100,000	185,000
1995	90,000	100,000	190,000
2000	85,000	100,000	185,000

Year 2000 total wood usage is projected to be 185,000 cords per year as compared to 155,000 cords/year in 1980 for a net growth of about 19%. However, wood burning in stoves and furnaces is projected to increase by 89% between 1980 and 2000, and fireplace wood usage is projected to drop by about 9%.

If ODEQ emission factors for stoves and fireplaces are assumed and no improvements in clean burning technology occur, year 2000 TSP emissions will increase by about 38% as compared to 1980, and almost all of this growth will occur in the next five years.

Table 9 shows the projections for wood usage and resultant emissions between 1980 and 2000 in five year intervals with assumed constant emission factors.

TABLE 9

Projected Change in Emissions
From
Seattle City Residential Wood Burning

	Stove / Furnace		**Fireplace**		**Total**	
Year	Wood Burned (Cd/yr)	TSP Emissions* (T/yr)	Wood Burned (Cd/yr)	TSP Emissions* (T/yr)	Wood Burned (Cd/yr)	TSP Emissions* (T/yr)
1980	45,000	1,770	110,000	1,925	155,000	3,695
1985	85,000	3,350	100,000	1,750	185,000	5,100
1990	85,000	3,350	100,000	1,750	185,000	5,100
1995	90,000	3,540	100,000	1,750	190,000	5,290
2000	85,000	3,350	100,000	1,750	185,000	5,100

* Assuming 1.75 tons wood/cord; fireplace and stove particulate emissions factors of 20 and 45 lb TSP/ton[20], respectively. Emission factors are assumed to remain constant. Improvements in stove efficiencies will reduce emission rates.

3. City of Spokane

The authors' best estimates of year 2000 total wood usage in Spokane city is about 129,000 cords per year. This represents the projections using BPA's most likely price escalation rates for oil, gas, and electricity, and a 2% real price escalation factor for wood. Table 10 presents year 2000 ranges of projected wood usage and best estimates for stoves/furnaces, fireplaces, and total wood usage. Table 11 shows the best estimate projections for years 1985, 1990, 1995, and 2000 for all three categories of wood usage.

TABLE-10

Projected Range of Year 2000 Wood Usage by Appliance
For the City of Spokane
(cords/year)

Appliance	Best Estimate
Stove/Furnace	54,000
Fireplace	75,000
Total Wood Usage	129,000

TABLE 11

Best Estimate Projection of Residential Wood Usage
for
The City of Spokane 1985 - 2000

Year	Stove/Furnace Wood Usage	Fireplace Wood Usage	Total Wood Usage
1980	28,000	93,000	121,000
1985	42,000	84,000	126,000
1990	45,000	81,000	126,000
1995	51,000	78,000	129,000
2000	54,000	75,000	129,000

Year 2000 total wood usage is projected to be 129,000 cords per year as compared to 121,000 cords/year in 1980 for a net increase of about 7%. However, wood burning in stoves and furnaces is projected to increase by about 93% between 1980 and 2000, and fireplace wood usage is projected to drop by about 19%.

If ODEQ emission factors for stoves and fireplaces are assumed and no improvements in clean burning technology occur, year 2000 TSP emissions will increase by about 26% as compared to 1980, and almost all of this growth will occur in the next five years.

Table 12 shows the projections for wood usage and resultant emissions between 1980 and 2000 in five year intervals with assumed constant emission factors.

A 14% increase in total emissions is projected between 1980 and 1985 even though the total amount of wood burned stays about the same. This is because airtight stoves are currently estimated to produce particulate emissions at more than twice the rate as in fireplace combustion.

TABLE 12

Projected Changes in Emissions from Spokane City Residential Wood Burning

	Stove / Furnace		Fireplace		Total	
Year	Wood Burned (Cd/yr)	TSP Emissions* (T/yr)	Wood Burned (Cd/yr)	TSP Emissions* (T/yr)	Wood Burned (Cd/yr)	TSP Emissions* (T/yr)
1980	28,000	1,100	93,000	1,630	121,000	2,730
1985	42,000	1,650	84,000	1,470	126,000	3,120
1990	45,000	1,770	81,000	1,420	126,000	3,190
1995	51,000	2,010	78,000	1,360	129,000	3,370
2000	54,000	2,130	75,000	1,310	129,000	3,440

* Assuming 1.75 tons wood/cord; fireplace and stove TSP emission factors of 20 and 45 lb/ton[20], respectively. Emission factors are assumed to remain constant. Improvements in stove efficiencies will reduce emission rates.

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   c. Mike Griggs, Washington Dept. of Natural Resources, Enumclaw , WA
   d. Tim Crotts, Weyerhaeuser, Inc., Enumclaw. WA
   e. Morey Vogle, USFS Information Office, Spokane, WA
   f. Gene Hollater; Darrell Evens, Colville National Forest
   g. Wayne Orr, Idaho Panhandle National Forest
   h. Phil Hildebrand, Washington Dept. of Natural Resources, Spokane, WA
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APPENDIX A

DETAILED DOCUMENTATION OF PROJECTION MODEL CALIBRATION

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DETAILED DOCUMENTATION OF PROJECTION MODEL CALIBRATION

At a minimum, application of Marshall's model to a particular area or region requires inputs of region specific information on local fuel prices, local annual BTU heating requirements, local population, etc. Additionally, some of the model's internal table functions defining relationships between key variables within the model's program must be modified since they assume New England type conditions, such as a 100 million BTU annual home heating requirement (the Pacific Northwest requirement is about half of that). Lastly, in the Pacific Northwest application of the model, a fireplace wood usage sector was added that was not included in the original model. These three categories of modifications are explained in detail; and model calibration documentation is provided for Seattle and Spokane:

- local condition inputs
- modifications to table functions
- addition of a fireplace wood usage sector
- model calibration (Seattle and Spokane only)

The application of the model to the Pacific Northwest could not have been achieved without the superlative job of model documentation presented throughout Norman Marshall's report. Rather than repeat his documentation in detail, those readers interested in the specific logic behind the original model are advised to obtain a copy of his report from the Resource Policy Center at Dartmouth College in New Hampshire.*

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*The Dynamics of Residential Wood-Energy Use in New England 1970-2000, June 1981 Masters Thesis by Norman Marshall.15 Available from the Resource Policy Center as RP#363, Thayer School of Engineering, Dartmouth College, Hanover, NH 03755.

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1. Portland Model Documentation

A. Local Condition Inputs

(1) Initial Households Total

260 C THI = 341,500

The number of households in the Portland-Vancouver metropolitan area in 1970 was 341,500.[4a]

(2) Household Growth Function

290 A HGF.K = TABLE (THGF, TIME.K, 1970, 2000, 5)
300 T THGF = .035/.030/.025/.023/.021/.019/.019

A local planning agency supplied the following data.[4a] The seven numbers in the table in Line 300 represent annual household growth rates at five-year intervals between 1970 percentages and 2000. Agency staff supplied household estimates of 341,505 for 1970, 471,850 for 1980 and 735,650 for 2000. The staff recommended that straight linear interpolation should be assumed rather than an exponential growth rate. These estimates of households were linearly interpolated at five year intervals, and the growth rates in Line 300 represent the annual growth rates which yield the above household values for 1980 and 2000.

(3) Initial Fraction of Households with Wood Heating

270 C IFHWC = .047

A 1970 estimate of the fraction of households heating with wood in Oregon was available in a 1980 paper by Esveldt and Roberts[21] of the Bonneville Power Administration. Lacking Portland data, this value was used as the baseline input. As an aside, year 2000 projection levels are not affected whether this initial input is varied between 1 and 5%.

(4) Heating Requirements Per Household

1040 A HRH.K = TABLE (THRH, TIME.K, 1970, 2000, 5)
1050 T THRH = 50E6/48E6/45E6/42.5E6/40E6/38.5E6/37.5E6

The values in Line 1050 represent that annual average household heating requirements dropped from 50 million BTU's in 1970 to 45 million BTU's in 1980 and will drop to 37.5 million BTU's per year in 2000. These figures represent a 25% drop in average household heating requirements between 1970 and 2000 which is consistent with the New England projection data in Marshall's model. The actual average heating requirement per household is difficult to know since a variety of estimates are available and depend on assumptions about age of the housing stock, type of fuel, efficiency, insulation levels, square footage assumptions, etc.

Northwest Natural Gas estimates that 1000 therms were needed to heat the average 1000 square foot house in 1972.[22] The average home sold in the

Portland area in 1980 had 1332 square feet, which suggests average gas requirements in 1972 would have been 1272 therms (source: Real Estate Report for Metropolitan Portland, Fall 1981. Clackamas = 1447 sq. ft.; Washington = 1413 sq. ft.; Multnomah = 1103 sq. ft.; Clark = 1365 sq. ft.; population weighted average of 1272 sq. ft.; Portland Real Estate Report, Box 19836, Portland, Oregon). At 40% (Oregon Department of Energy)[23] to 50% (Marshall, and Gas Appliance Manufacturer's Association, Arlington, VA)[24] heating efficiency, this would yield a 1972 heating requirement estimate of 51 to 64 million BTU's per year.

However, ODOE estimates heating requirements for electrically heated residences in 1970 to be 11,600 kwh/year, which at 95% efficiency (5% duct losses) equals a heating requirement of only about 38 million BTU's per year.

ODOE estimates oil heating requirements were 876 gallons/year in 1970, which at 40% efficiency[23] and 136,000 BTU/gallon would yield a heating requirement of 48 million BTU's per year. However, at 50% efficiency (Marshall, and Glenn Harding of the Oil Heat Institute of Oregon)[25] this would yield a heating requirement of 60 million BTU's per year.

Based on best engineering judgement, an initial heating requirement of 50 million BTU's per household in 1970 was assumed, together with a 25% reduction in average heating requirements over the following 30 years. The values in Line 1050 represent exactly 50% of the values in Marshall's New England version of the model.

(5) Adjustment to Real Prices Based on the Consumer Price Index

For consistency, all historical fuel prices are input into the model in 1980 constant dollars. Specific consumer price index figures for the Portland metropolitan area for 1970 through 1980 were obtained from the San Francisco office of the U.S. Bureau of Labor Statistics (415-556-4678), and these values were used to adjust historical fuel prices to the constant basis of 1980 dollars. The consumer price index figures for the Portland metropolitan area are shown in Table 13 for the 1970 to 1980 period.

TABLE 13

Portland Metropolitan Area
Consumer Price Index 1970-1980

1970	110.6
1971	114.9
1972	118.1
1973	121.8
1974	133.9
1975	152.5
1976	162.1
1977	172.4
1978	187.9
1979	211.7
1980	244.6

(6) Historical Oil Prices

```
1160 A OP1.K=TABHL(TOP1,TIME.K,1970,1980.1)
1170 T TOP1=.409/.424/.422/.480/.581/.597/.634/.609/.585/.821/.974
```

Historical distillate oil prices for the Portland area were obtained from the Oil Heat Institute. Table 14 shows prices in actual dollars (rather than real 1980 dollars) in Column 2 with prices in real 1980 dollars shown in Column 3.

TABLE 14

Historical Portland Area Oil Prices
in Actual and 1980 Dollars
(Price/Gallon)

Year	Actual Price ($)	Price in 1980 ($)
1970	.185	.409
1971	.199	.424
1972	.204	.422
1973	.239	.480
1974	.318	.581
1975	.372	.597
1976	.420	.634
1977	.429	.609
1978	.449	.585
1979	.711	.821
1980	.974	.974

(7) Historical Gas Prices

```
1250 A GP1.K=TABHL(TGP1,TIME.K,1970,1980,1)
1260 T TGP1=2.82/3.22/3.61/3.86/4.01/4.09/4.65/5.13/5.46/5.53/5.43
```

Historical gas prices for the Portland area were obtained from Northwest Natural Gas.22 1970 to 1980 prices in actual and 1980 dollars per therm are shown in Table 15.

TABLE 15

Historical Portland Area Gas Prices In Actual and 1980 Dollars ($/Therm = $$10^5$ BTU's)

Year	Price in 1980 ($)
1970	2.82
1971	3.22
1972	3.61
1973	3.86
1974	4.01
1975	4.09
1976	4.56
1977	5.13
1978	5.46
1979	5.53
1980	5.43

(8) Historical Electricity Prices

```
1340 A EP1.K=TABHL(TEP1,TIME.K,1970,1980,1)
1350 T TEP1=.02212/.0213/.0207/.0279/.0287/.0314/.0343/.0355/.0335/.0313/.037
```

Historical electricity prices for the Portland area were obtained from Portland General Electric[27] and Pacific Power and Light.[28] These values, in $/kwh in actual cost are shown for both utilities in Table 16.

TABLE 16

Portland Area Actual Electricity Prices, 1970-1980($/kwh)

Year	PPL Prices*	PGE Prices#
1970	.01466	.008
1971	.01465	.008
1972	.01466	.008
1973	.01466	.0136
1974	.01755	.0149
1975	.0867	.0200
1976	.02350	.0224
1977	.02724	.0240
1978	.02802	.02477
1979	.02969	.02584
1980	.03409	.03912

* PPl rates based on usage of 1000 kwh/month.
# PGE rate in 1973, 1974, and 1975 are slightly higher for usage above 400,400 and 300 kwh/month. Thus weighted prices were calculated for those years.

Since PPL and PGE in 1980 served 30.2% and 69.8% of the households in the Portland area, the prices in Table 16 above were weighted in those proportions to derive average prices in the region. Table 17 shows those weighted prices in actual dollars in Column 2 and in 1980 dollars in Column 3.

TABLE 17

Portland Metropolitan Area Weighted Average
Electricity Costs in Actual and 1980 Dollars
($/kwh)

Year	Actual Price	1980 Price
1970	.0100	.0221
1971	.0100	.0213
1972	.0100	.0207
1973	.0139	.0279
1974	.0157	.0287
1975	.0196	.0314
1976	.02274	.0343
1977	.0250	.0355
1978	.02575	.0335
1979	.02701	.0313
1980	.03761	.0376

(9) Historical Wood Prices

```
1440 A WP1.K=TABHL(TWP1,TIME.K,1970,1980,1)
1450 T TWP1=55/53/62/70/73/75/83/89/101/98/90
```

Wood prices per cord for each of the years 1970 through 1980 were determined by a review of average prices advertised in the Classified Section of the Oregonian between December 1st and 15th of each of those years. Table 18 shows those prices in actual cost in Column 2 and in 1980 cost (via CPI) in Column 3.

TABLE 18

Wood Prices 1970-1980 in Actual and 1980 Dollars
($/cord)

Year	Actual Dollars[29]	1980 Dollars
1970	25	55
1971	25	53
1972	30	62
1973	35	70
1974	40	73
1975	47	75
1976	55	83
1977	63	89
1978	78	101
1979	85	98
1980	90	90

(10) Historical Conventional Fuels Usage Split

```
1070 A FCFO.K=TABLE(TFCFO,TIME.K,1970,2000,5)
1080 T TFCFO=.458/.391/.301/.26/.235/.217/.200
1090 A FCFG.K=TABLE(TFCFG,TIME.K,1970,2000,5)
1100 T TFCFG=.256/.262/.263/.25/.25/.25/.25
```

Since the model compares wood heating costs to average costs of heating with conventional fuels, the costs of the different conventional fuels must be weighted in proportion to households that heat with those various fuels. However, this split information was only available for 1975 and 1980 for Oregon as a whole. Since Bureau of Census data was available for the Portland metropolitan area for 1970, the fuel splits for year 1975 and 1980 were derived by projecting changes in Portland area fuel splits based on how the splits for the whole state of Oregon changed between 1970 and 1980. Table 19 below shows the resulting estimated relative usage of conventional fuels.

TABLE 19

Portland Area Shares of Household Heating
Via Conventional Fuels, 1970-1980*
(Shares Relative to 1.00)

Year	Oil Heating	Gas Heating	Electricity Heating
1970	.458	.256	.285
1975	.391	.262	.347
1980	.301	.263	.436

*The fraction of conventional heating from oil and gas are input in the model in Lines 1080 and 1100, respectively. Electricity shares are calculated in the model by difference. Splits for 1985, 1990, 1995, and 2000 are also input in these same line numbers as explained in the following.

(11) Future Conventional Fuel Usage Split

Future projections for the splits between usage of conventional fuels was only available for the state of Oregon as a whole.[30] Therefore, the 1980 split for the Portland area was adjusted for future year split projections based on how the statewide splits are projected to change. Table 20 shows those future year projections.

TABLE 20

Portland Area Projected Shares of Household Heating
Via Conventional Fuels, 1985-2000#
(Shares Relative to 1.00)

Year	Oil Heating	Gas Heating	Electric Heating
1985	.26	.252	.488
1990	.235	.252	.513
1995	.217	.251	.532
2000	.200	.249	.551

#Oil and gas data are input in Lines 1080 and 1100, respectively. Electricity share is calculated in the model by difference.

(12) Future Oil and Gas Prices

```
1180 A OP2.K=TABHL(TOP2,TIME.K,1980,2000,2.5)
1190 T TOP2=.974/1.09/1.213/1.30/1.388/1.512/1.636/1.705/1.773
1270 A GP2.K=TABHL(TGP2,TIME.K,1980,2000,2.5)
1280 T TGP2=5.43/6.30/7.17/7.82/8.53/9.30/10.13/10.94/11.81
```

ODOE has published projections for real rates of price increase for residential distillate oil and natural gas.[31] These price projections were used to derive the oil and gas price projections shown in Table 21. Table increments are 2.5 years to be consistent with the model's input requirements.

TABLE 21

Projected Portland Area Future Residential Oil and Gas Prices

Year	(1980 dollars/gallon) Oil Price	(1980 dollars/therm) Gas Price
1980	.974	5.83
1982.5	1.09	6.30
1985	1.213	7.17
1987.5	1.30	7.82
1990	1.388	8.53
1992.5	1.512	9.30
1995	1.636	10.13
1997.5	1.705	10.94
2000	1.773	11.81

(13) Future Electricity Price

```
1360 A EP2.K=TABHL(TEP2,TIME.K,1980,2000,2.5)
1370 T TEP2=.0376/.0387/.0399/.0415/.0432/.05184/.0608/.06446/.06902
```

The Bonneville Power Administration (Division of Power Requirements, Division of Conservation) has projected future electricity prices for private utilities. Since BPA is the designated agency for regional energy planning, the electricity price escalation factors from BPA's "Pacific Northwest Electric Energy Model"[32] (7/30/81 run, still the most recent version available on 11/23/81) were used to project future electricity prices. Projected real price escalation factors are 80-85:1.0503, 85-90:1.0839, 90-95:1.4076, and 95-2000:1.0949. Electricity price projections are shown in Table 22 with table entries 2.5 years apart to be consistent with model input format.

TABLE 22

Future Portland Area Electricity Price Projections
($/kwh)

Year	Price in 1980 $
1980	.0376
1982.5	.0387
1985	.0399
1987.5	.0415
1990	.0432
1992.5	.05184
1995	.0608
1997.5	.06446
2000	.06902

(14) Future Wood Prices

```
1460 A WP2.K=TABHL(TWP2,TIME.K,1980,2000,2.5)
1470 T TWP2=90/95/99/104/109/115/121/127/133
```

No official government agency price projections were available for residential cord wood. Neither the Wood Heating Alliance, Wood Energy Association, nor the U.S.F.S.'s Ken Scog were aware of any such projections. Accordingly, the base case wood price escalation factors from Marshall's New England work (2%/year real price growth) were assumed to apply. Some researchers have noted wood applications that aid energy conversation and have suggested wood prices will escalate as fast as conventional energy prices. During the 1980 to 2000 period, conventional fuel prices in the Portland area are projected to increase at an annual rate of 2.08%. Thus, a wood price escalation rate of 2%/year seems reasonable, and was therefore utilized. Table 23 shows wood price projections for 1980-2000 again in 2.5 year increments to be consistent with model input requirements.

TABLE 23

Portland Area Wood Price Projections 1980-2000
($/cord)

Year	Price
1980	90
1982.5	95
1985	99
1987.5	104
1990	109
1992.5	115
1995	121
1997.5	127
2000	133

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(15) Fuel Conversion Efficiencies

```
1130 A OE.K=TABLE(TOE,TIME.K,1970,2000,5)
1140 T TOE=.5/.5/.55/.575/.6/.625/.65
1310 A EE.K=TABLE(TEE,TIME.K,1970,2000,5)
1320 T TEE=.95/.95/.95/.95/.95/.95/.95
1220 A GE.K=TABLE(TGE,TIME.K,1970,2000,5)
1230 T TGE=.6/.6/.6/.625/.65/.675/.7
```

TABLE 24

Efficiency of Heating with Conventional Fuels
(relative to 1.00)

Year	Gas	Oil	Electricity
1970	.600	.500	.95
1975	.600	.500	.95
1980	.600	.55	.95
1985	.625	.575	.95
1990	.650	.600	.95
1995	.675	.625	.95
2000	.700	.650	.95

B. Explanation of Table Functions Adjusted

In systems dynamics modeling, simulated relationships are often attempted that difficult to define in the form of a y=x, etc. equation. In systems dynamics work in the Dynamo programming language, in cases where the general relationship between factors is thought to be understood, table functions are often employed to quantify the relationship between variables. For example, one variable named TEMPWIC, which stands for "The effect of market penetration on wood installation cost," is used to represent the relationship that wood installation cost increases as more of the market is penetrated (since the easiest and cheapest installations are the first ones generally to install wood stoves). The particular program lines which specify this relationship are:

```
450 A EMPWIC.K = TABLE (TEMPWIC,HWC.K/TH.K,0,1,2)
460 T TEMPWIC  = 1/1.5/3/5/5/5
```

Without explaining all the details about Dynamo programming language, the reader can note that the variables generally are a mnemonic device that abbreviates the variables they represent. HWC and TH refer to "households with wood capacity" and "total households," respectively. The degree of market penetration ranges from 0 to 1.00 and represents the fraction of houses with wood capacity divided by total households. Table 25 shows in more conventional format the relationship which is defined by Lines 450 and 460.

TABLE 25

Market Penetration Table

Market Penetration or Fraction of (Stove) Installation Capacity Is Expected to Increase	Multiplier by Which Baseline Wood Households with Wood Capacity
0	1.0
.2	1.5
.4	3.0
.6	5.0
.8	5.0
1.0	5.0

Now that this introduction has been completed of how table functions are used in the program, it is appropriate to explain which table functions were changed in the model and on what basis. Marshall's report *The Dynamics of Residential Wood Usage in New England 1970-2000* provides complete documentation of why various table functions were used, etc. Readers interested in understanding the model in detail can review that work. The following discussion explains only those table functions that were modified for the Portland area.

Marshall specifies which table functions that should be modified when applying the model to other areas. Those variables (asterisked) and the others modified are listed in Table 26 along with an explanation the variable.

TABLE 26

Variables Modified in Portland Model Runs

*TNWIC	Table for Normal Wood Installation Cost
TCFI	Table for Capacity Fraction Installed
*TCIWC	Table of the Cost of the Inconvenience of Wood from Capacity
*TESCWP	Table for the Effect of Self Cut Wood on Price
TFCIWC	Table which defines the Fraction (of households) from Cost (i.e. potential savings with wood heat) which will Install Wood Capacity

(1) Normal Wood Installation Cost (TNWIC)

In the New England version of the model, the following tabular relationship is employed.

Capacity Fraction Installed	Normal Wood Installation Cost
0	200
.2	300
.4	400
.6	600
.8	1000
1.0	1500

Since the annual BTU heating requirement For the Portland metropolitan area is half of that in the New England model, the cost of installing 100% wood heating capacity was assumed to be exactly half of the value for New England, or $750. The cheapest stoves available in the Portland area are about $200. Thus, these end-points were used for the Portland area and intermediate values for .2, .4, .6, and .8 capacity were derived by assuming similar ratio interpolations for the intermediate points. The Portland area relationship is shown in Table 27. Note the cost of installing 60% capacity is set to equal $370, or $200 plus 400/1300 of the magnitude between the table end points (750-200), analogous to how the $600 cost for 60% capacity in New England equals 200 plus 400/1300 times the magnitude between table end points, which is 1500 minus 200, or 1300. This type of interpolation, rather than linear interpolation is appropriate because the cost of increasing capacity installed from 80% to 100% is higher than the differential cost of increasing installed capacity from 20% to 40%.

TABLE 27

Portland Area Normal Wood Installation Cost
Versus Capacity Fraction Installed

Capacity Fraction Installed	Normal Wood Installation Cost
0	200
.2	240
.4	285
.6	370
.8	540
1.0	750

The specific lines in the model which incorporate this relationship are shown below.

```
470 A NWIC = TABLE (TNWIC, CF1.K, 0, 1, .2)
480 T TNWIC = 200/240/285/370/540/750
```

(2) Capacity Fraction Installed (TCFI)

This table function represents how the capacity fraction installed by households varies as the average fuel cost savings varies. Table 28 shows the relationship in the New England version.

TABLE 28

New England Average Fuel Cost Savings	vs.	Capacity Fraction Installed
-200		.2
0		.3
200		.4
400		.6
600		.8
800		.9
1000		.95

This table function was changed in the Portland model. With only a 50 million BTU heating requirement in the Portland area as compared to a 100 million BTU requirement in New England, fuel cost savings will necessarily be less and a certain capacity fraction represents different sizes of heating equiment. For example, 90% capacity fraction represents 90 million BTU's heating capacity in New England, but only 45 million BTU's heating capacity in the Portland area.

For the Portland area, the following table function was employed:

TABLE 29

Portland Area Average Fuel Cost Savings
vs. Capacity Fraction Installed

Average Fuel Cost Savings	Capacity Fraction Installed
-100	.5
0	.6
100	.7
200	.8
300	.9
400	.95
500	.95

The basis for these table values is as follows. Based on the New England table, a -$100 savings is associated with installation of 25% capacity which is a stove with 25 million BTU's capacity. For Portland, it was similarly assumed a -$100 savings was associated with a 25 million BTU stove, but this represents 50% capacity. Also, in New England, a $200 savings is associated with 40%

capacity installation, which is 40 million BTU's. In Portland, a $200 savings is associated with a 40 million BTU capacity stove, but this represents 80% capacity. The maximum capacity fraction installed values are set at 95% since stoves commonly have trouble heating a house 100% (the systems for transferring heated air are often less sophisticated than with conventional fuel heating equipment). This paragraph explains rows 1, 4, and 6 and 7 of Table 24; remaining table values were interpolated.

The model line numbers which incorporate these table values are:

```
520 A CF1.K = TABLE (TCFI, AFCS.K, -100, 500, 100)
530 T TCFI = .5/.6/.7/.8/.9/.95/.95
```

(3) Cost of the Inconvenience of Wood from Capacity (TCIWC)

The model incorporates a variable TCIWC which stands for the Cost of the Inconvenience of Wood due to Capacity utilized representing the relationship that wood heating inconvenience costs go up as a greater percentage of home heating is achieved via wood. Table 30 shows the New England values assumed in Column 2 and the Portland area values assumed in Column 3. Portland values were simply set at 50% of the New England values since the heating requirement, and therefore the amount of wood heating and associated inconvenience, is only 50% for the Portland area compared to New England (50 vs. 100 million BTU's/year).

TABLE 30

Relationship Between Capacity Fraction Installed
and the Cost of Inconvenience of Wood due to Capacity Utilized

Wood Heating Capacity Utilized	New England CIWC	Portland CIWC
0	200	100
.2	300	150
.4	500	250
.6	800	400
.8	1000	500
1.0	1000	500

The line numbers in the Portland model that represent these values are shown below. Capacity utilized in Line 990 is the fraction AC/HRH or average capacity/household heat requirement.

```
990 A CIWC.K = TABLE (TCIWC, AC.K, HRH.K, 0, 1, .2)
1000 T TCIWC = 100/150/250/400/500/500
```

(4) Effect of Self Cut Wood on Price (TESCWP)

The TESCWP variable stands for the Effect of Self Cut Wood on Price and represents the relationship that people perceive their wood acquisition costs are less when they can cut their own wood rather than having to purchase it.

The amount of forest resources available per capita is considerably higher in Oregon than in the New England states. For example, the average amount of "cords of growing timber stock per household" is 1104 in Oregon versus only 80 in New England.* Also the amount of "growing stock growth in cords per household" is 15.7 in Oregon versus only 1.03 in New England.* Thus it was assumed reasonable to use a different "self-cut wood effect on price" variable for the Portland area which would result in perceived price being somewhat lower in Oregon than in New England. Table 31 shows the table function values assumed for New England in Column 2 and the Portland area in Column 3.

*Marshall, *op.cit.*, citing the USDA Forest Service, *Forest Statistics of the U.S., 1977*, Washington, D.C., 1978, p. 1-2, 33-34, 97-98.

TABLE 31

The Effect of Self Cut Wood on Price Versus Wood Heating Penetration

Market Penetration	ESCWP New England	ESCWP Portland
0	.5	.4
.2	.8	.5
.4	1.0	.8
.6	1.0	1.0
.8	1.0	1.0
1.0	1.0	1.0

One additional modification was employed. In the New England model version, penetration was defined as the ratio of houses with wood capacity to total households. However, since the 1980 to 2000 growth rate in households is projected to be considerably higher in the Portland area (56% vs. 22%), this more rapid household growth rate has the effect of reducing the parameter that measures penetration even though the number of households competing for available self-cut wood resources is steadily increasing. In the Portland version penetration was defined as the ratio of households heating with wood divided by the original number of households in 1970 (HWC/THI or households with wood capacity/total households initial).

The model line numbers which incorporate these table values for the Portland area are shown below:

```
1480 A ESCWP.K = TABLE (TESCWP, HWCK/THI, 0, 1, .2)
1490 T TESCWP = .4/.5/.8/1/1/1
```

(5) Fraction (of households) from Cost that Will Install Wood Capacity (TFCIWC)

The TFCIWC variable represents the Fraction (of households) From Cost (i.e. based on payback period) that will Install Wood Capacity. Based on the payback period that a new wood installation represents a certain fraction of households will install wood heating capacity. Since Portland area annual heating costs are about half of New England costs, this author perceived that slightly fewer Portland households would be motivated to install wood heating even with the same payback period. Thus, a slightly lower installation response rate was assumed for the Portland area. Figure 11 shows the table function in graphical form for the two areas and Table 32 shows the relationship in tabular format.

Year 2000 projected wood usage is exactly the same, regardless of the Portland or New England values used, but the 1970 to 1980 Portland wood use pattern fits known historical values better with the Portland curve, which tends to confirm the hypothesis that the true relationship for Portland is closer to the values in Column 3.

C. Fireplace Wood Usage Sector

As explained in the text, several factors are expected to motivate less wood burning in fireplaces. 1) As fireplaces are converted to more efficient stove installations, fireplace wood burning should drop. 2) If real wood prices escalate rapidly, aesthetic burning of wood should also drop. Burning in a simple fireplace at from negative to 20% efficiency does not have as attractive a return on investment (in wood burned) as stoves.

In order to gain insight into how fireplace wood usage has been changing in the late 1970's, it was decided to review several available surveys with multiple year data. The best and largest available data base is a 5600 household survey, the New England Fuelwood Survey, conducted by the U.S. Department of Agriculture, Economics, Statistics, and Cooperatives Service, published in 1980. According to this survey, fireplace wood usage dropped by 18% between the 1976-77 and the 1978-79 heating seasons.

As additional corroboration of this trend, a comparison between the Talbot Wong survey results for the Medford area for winter 1977-78 vs. an Oregon DEQ survey for winter 1980-81 indicated an average annual wood usage per fireplace of 2.15 cords for the winter 1977-78 period vs. 1.26 cords for the latter period. Although the two survey methodologies and questions format are slightly different, this drop in average usage per fireplace confirmed the expected drop in wood usage per fireplace.

Norman Marshall was consulted as to what might be the best factors to use to project future fireplace usage. He suggested that the most simple and straightforward method would be to have fireplace wood usage drop in proportion to increases in average wood prices. A review of New England wood prices during the two year period when an 18% drop in fireplace wood usage occurred showed that prices for wood (in constant 1980 dollars) increased about 12% during that same time period. The assumption that an elasticity relationship of a 1.5% fireplace wood usage drop for each 1% price increase was considered, but this (based on the 18% to 12% ratio) methodology would predict fireplace wood usage dropping to zero if prices increased 67%. The New England wood prices available and used in Marshall's model were actually New Hampshire wood prices. The New England price increase could have been close to 18%. Thus, it was decided to set future fireplace wood usage equal to base 1977 wood usage times the ratio of 1977 wood price over future year wood price. In the example for the Portland metropolitan area assuming a year 2000 wood price of $130/cord,

Figure 11 Wood Installations vs. Payback Period

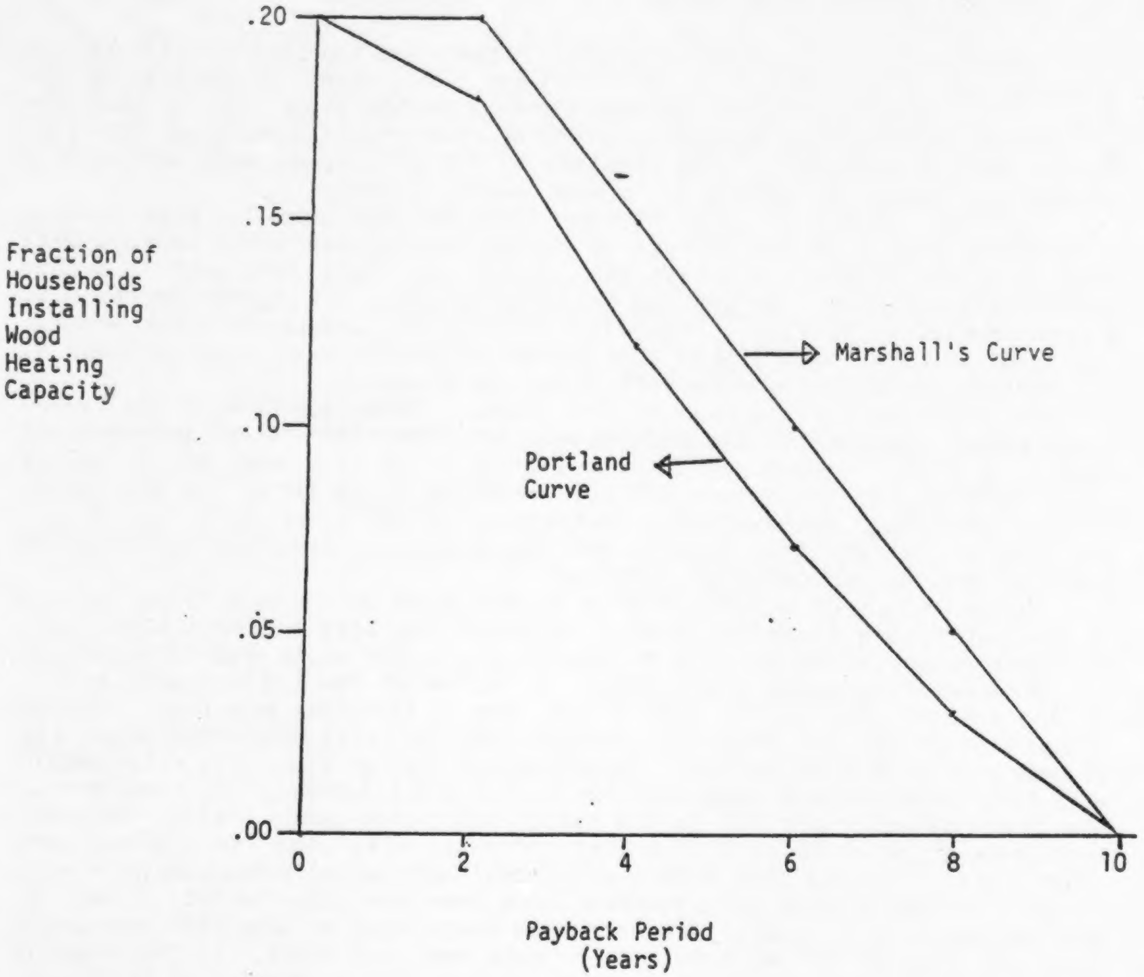


TABLE 32

Wood Installations vs. Payback Period

Payback Period	New England Fraction of Households Installing Wood Capacity	Portland Area Fraction of Households Installing Wood Capacity
0	.2	.2
2	.2	.18
4	.15	.12
6	.10	.07
8	.05	.03
10	0	0
12	0	0
14	0	0
16	0	0
18	0	0
20	0	0

$$\text{2000 Fireplace Wood Usage} = \text{1977 fireplace wood usage}\ \frac{\text{(1977 wood price)}}{\text{(2000 wood price)}}$$

$$= 219{,}000\ (\$86/\$130) = 145{,}000 \text{ cords}$$

Since no data was available on fireplace wood usage prior to 1977, the simple assumption was made that 1970 through 1977 fireplace wood usage remained constant. This methodology could be improved by mathematically linking a certain fraction of new stove installations to a rate of fireplace "decommissioning," but given the limited scope of the original task (which did not include computer model projections) as well as the uncertainties about true elasticities it was decided to incorporate this simple relationship.

The code below shows the code which was inserted into the Portland version of Marshall's model. All additions to the code were inserted between lines 1700 and 1720 so that the line numbers of the balance of the Portland code in the model still correspond exactly to line numbers used originally by Marshall with this one exception. In order to change this code regarding input values, the four occurrences of the value "209,000" (1977 fireplace wood usage) should all be changed to whatever alternate initial fireplace usage is assumed, and the 1977 wood price value in Line 1706 (86, in this case) altered to the appropriate value.

```
1701 NOTE
1702 NOTE FIREPLACE USAGE MODULE
1703 NOTE
1704 NOTE
1706 A WPR.K=86/BWP.K
1708 A DWPR.K=DLINF1(WPR.K,FCSAT)
1710 N FWU2=209000
1712 A FUD.K=209000*(1-DWPR.K)
1714 A FWU.K=CLIP(FWU1.K,FWU2.K,1977,TIME.K)
1716 A FWU1.K=209000
1718 A FWU2.K=209000-FUD.K
1720 A TWU.K=FWU.K+WU.K
```

2. SEATTLE MODEL DOCUMENTATION

In order to fully understand this section, the reader is advised to first read the documentation for the Portland modeling work (in Appendix). This section explains only modifications made to the Portland version of the model.

A. Local Condition Inputs

(1) Historical Wood Usage

Historical wood usage is discussed in Sections 2(D)(1) and 2(D)(2) of this Appendix, page A2-9 through A2-11.

(2) Household Heat Requirement

A direct estimate of average household heating requirements was not available from either BPA, the Seattle Energy Office, or the Washington Department of Natural Resources. Therefore, the heating requirements determined for Portland were scaled based on heating degree averages. Since King County (Seattle) has heating degree days of 4447 (Washington Energy Use Profile) compared to the Portland area average of 5036, the Seattle household heating requirement was assumed to be 44.2 million BTU's/year (50 million x 447/5036). This is input in the model using the code below:

```
890 C HRHI = 44.2E6
```

(3) Household Growth Function

Estimates for households in the city of Seattle were available for 1970 and 1930. These were interpolated to derive a 1975 estimate. Population projections were available for the combination of King plus Snohomish County (Seattle SMSA). These projection rates were used to project future households after 1980 in Seattle. Table 33 shows the SMSA projections in Column 1, those projections relative to 1.00 in Column 2, and resultant projections for the number of households in Column 3.

TABLE 33

Seattle Area Population and Household Projections

Year	SMSA Population	Growth Relative to 1.00	Households in Seattle
1970	NA	NA	206,100
1975	NA	NA	213,050
1980	1,606,495	1.000	220,000
1985	1,797,946	1.119	246,180
1990	1,969,967	1.226	269,720
1995	2,149,748	1.338	294,360
2000	2,360,356	1.469	323,180

(4) Initial Fraction of Households with Wood Heating

Data available from the 1970 Census of Housing indicated that .16% of households relied on wood as their primary heat source in 1970. This was input in Line 270 using the code below:

```
270 c IFHWC = .0016
```

(5) Heating Requirements

Since Seattle area household heating requirements were determined to be 84.4% of Portland heating requirements, future heating requirements were set at 84.4% of the future heating requirements estimates for Portland or 42.2% of the requirements determined for New England households. This was input in Line 1050 using the code below.

```
1050 T THRH = 44.2/42.4/39.8/37.6/35.4/34.0/33.2
```

(6) Adjustment to Real Prices Based on the Consumer Price Index

All historical fuel prices were input into the model in 1980 constant dollars. Specific C.P.I. data for the Seattle area was obtained from the San Francisco Office of the U.S. Bureau of Labor statistics (415-556-4678). Seattle C.P.I. figures for 1970 to 1980 are shown in Table 34.

TABLE 34

Seattle Metropolitan Area Consumer Price Index 1970-1980

1970	112.5
1971	14.6
1972	119.0
1973	123.1
1974	135.8
1975	1.8
1976	161.7
1977	1.4
1978	184.1
1979	202.0
1980	236.0

(7) Historical Oil and Gas Prices

Historical oil prices were obtained from the Oil Heat Institute of Washington. Actual prices are shown in Table 35 in Column 1 with prices in real 1980 dollars shown in Column 2. Historical gas prices were obtained from Washington Natural Gas. Historical gas prices are shown in Column 3 with CPI adjusted prices in Column 4.

TABLE 35

Historical Oil and Gas Prices in the Seattle Area

Year	Actual Oil Price ($/gallon)	Oil Price, 1980$ ($/gallon)	Actual Gas Price ($/$10^6$ BTU)	Gas Price, 1980$ ($/$10^6$ BTU)
1970	.206	.432	1.56	3.27
1971	.214	.441	1.597	3.29
1972	.227	.450	1.612	3.20
1973	.254	.487	1.665	3.19
1974	.344	.598	1.923	3.34
1975	.409	.636	2.573	4.00
1976	.463	.676	2.889	4.22
1977	.473	.651	3.216	4.43
1978	.495	.635	3.563	4.57
1979	.786	.918	4.267	4.98
1980	1.079	1.079	5.118	5.12

(8) Historical Electricity Prices

Historical electricity prices were obtained from Seattle City Light in Seattle. Actual prices are shown in Table 36, Column 1, with prices in real 1980 dollars in Column 2.

TABLE 36

Historical Electricity Prices in the Seattle Area

Year	Actual Price ($/kwh)	Real 1980 $ Price ($/kwh)
1970	.00862	.0181
1971	.00858	.0177
1972	.00858	.0170
1973	.00858	.0164
1974	.00922	.0160
1975	.00922	.0143
1976	.00922	.0135
1977	.01174	.0162
1978	.01174	.0151
1979	.01174	.0137
1980	.02069	.02069

(9) Historical Wood Prices

Historical wood prices for Seattle were obtained for 1970, 1975, and 1980 from the Seattle Post-Intelligence Classified Section. These values were converted to 1980 real prices via the Consumer Price Index, and intermediate year values derived via interpolation as shown in Table 37.

TABLE 37

Historical Seattle Area Wood Prices

Year	Actual Price ($/cord)	Real Price (1980 $/cord)
1970	29	61
1971		62
1972		64
1973		66
1974		68
1975	45	70
1976		75
1977		80
1978		85
1979		90
1980	94	94

The values in column 3 were input into the model using the code below:

```
1450 A TWPI = 61/62/64/66/68/70/75/80/85/90/94
```

(10) Historical and Projected Fuel Use Split

The 1970 Census of Housing provided information on the distribution of oil, gas, and electricity usage (as the primary heat source) in occupied housing units. Those values are shown in Row 1 in Table 38. For the 1980 or current fuel split for conventional fuels, the best available information source is the Seattle City Light Survey (1979). 1980 fuel usage was assumed to be split in the same proportion as from the S.C.L. data for fall 1979. This information is shown in Row 3 below. The 1975 fuel split was derived by interpolating between 1970 and 1980 and is shown in Row 2 below. For future year fuel split projections, the only source obtained for the Pacific Northwest was ODOE projections* for future state of Oregon fuel splits. Based on how oil, gas, and electricity usage is projected to change in Oregon from 1980 to 2000, the Seattle area splits were projected to change in the same proportion by 2000. The year 2000 derived split was normalized to sum to 1.00 and values for years 1985, 1990, and 1995 derived by interpolation. The 1985-2000 values for each fuel share are shown in Rows 4 through 7.

TABLE 38

Historical and Projected Fuel Use Split in the Seattle Area
(Relative to 1.00)

Year	Oil Use	Gas Use	Electricity Use
1970	.530	.249	.221
1975	.460	.240	.300
1980	.389	.230	.481
1985	.351	.223	.501
1990	.314	.216	.521
1995	.276	.208	.541
2000	.238	.201	.561

*ODOE Oregon's Energy Future, op. cit., p. 100

Only the values for oil and gas are input into the model with electricity shares derived by difference. Lines <u>1080</u> and <u>1100</u> input the oil and gas splits in the model, respectively, as shown in the code below:

```
1080 T TFCFO = .53/.46/.389/.351/.314/.276/.238
1100 T TFCFG = .249/.24/.23/.223/.216/.208/.201
```

(11) Future Oil and Gas Prices

Future oil and gas prices were based on real price growth rate projections for the Pacific Northwest by BPA.* These projected real prices are shown in Table 39. Values are shown in 2.5 year increments to be consistent with model input requirements.

TABLE 39

Projected Real Prices for Oil and Gas in the Seattle Area

Year	Real Oil Price (1980 $/gallon)	Real Gas Price (1980 $/$10^6$ BTU)
1980	1.079	5.12
1982.5	1.200	5.93
1985	1.343	6.73
1987.5	1.430	7.36
1990	1.538	8.01
1992.5	1.665	8.74
1995	1.812	9.48
1997.5	1.880	10.24
2000	1.964	11.03

The data in Columns 2 and 3 above are input into the model using the code below:

```
1190 T TOPZ = 1.079/1.20/1.343/1.43/1.538/1.655/1.812/1.88/1.964
1280 T TGPZ = 5.12/5.93/6.73/7.36/8.01/8.74/9.48/10.24/11.03
```

(12) Future Electricity Prices

The real electricity price growth rate projections developed by BPA for public utilities in the Pacific Northwest** were used to project future electricity rates for Seattle. The escalation factors and resultant projections are shown in Table 40:

---

*BPA, <u>Economic, Demographic Projections of the Pacific Northwest</u>, op. cit., p. 147.

**BPA <u>Pacific Northwest Electric Energy Model</u>, op. cit.

TABLE 40

BPA Electricity Price Growth Rates and
Resultant Seattle Area Projections

Year	Growth Rate Projections for Public Utilities (1980=1.000)	Seattle Area Projected Electricity Prices ($/kwh)
1980	1.000	.0208
1982.5	1.078	.0223
1985	1.155	.0239
1987.5	1.291	.0267
1990	1.427	.0295
1992.5	1.473	.0305
1995	1.519	.0314
1997.5	1.5825	.0327
2000	1.646	.0339

The values in Column 3 are input into the model using the code below:

```
1370 T TEPZ = .0207/.0223/.0239/.0267/.0295/.0305/.0314/.0327/.0339
```

(13) Future Wood Prices

As for the other cities in this projection study, a 2% real wood price escalation factor was assumed and results input into the model using the code below for years 1980 through 2000 in 2.5 years increments.

```
1470 T TWPZ = 94/99/104/109/114/120/126/132/139
```

B. Explanation of Table Functions Adjusted

Only two of the "relationship table functions" were changed for the Seattle runs. Since heat requirements are lower, the same stove installation represents installation of a higher fraction of potential wood heating capacity (closer to 1.00). Thus, for a given fraction of capacity installed (i.e., 60% of household heating requirements) the inconvenience of wood heating should be slightly lower for that fraction of capacity and the wood stove installation cost slightly lower (as compared to the wood use and stove size needed to provide 60% of heating requirements in Portland or New England). The two functions changed were TCIWC and TNWIC.

(1) Cost of the Inconvenience of Wood from Capacity (TCIWC)

This function expresses how the cost of the inconvenience of wood due to capacity increases as the capacity fraction installed increases. As explained for TCIWC in the Portland section of the Appendix, the New England table values were simply ratioed downward in proportion to the ratio between Seattle household heating requirements (44.2 x 10^5 BTU's/year) and New England heating requirements (100 x 10^5BTU's/year) in 1970.

The resultant code is shown in line 1000 below:

```
1000 T TCIWC = 88/133/220/354/440/440
```

(2) Normal Wood Installation Cost (TNWIC)

Since heat requirements are less, the size of stove (and therefore cost) that must be purchased to provide 100% capacity is therefore less. The cost of 100% capacity was adjusted by the ratio of Seattle to New England Heating Requirements ($1500 x 44.2/100), and the cheapest stove available was still assumed to be $200. Intermediate values were interpolated based on the proportions in the original New England function. The resultant code is shown below:

```
480 T TNWIC = 200/235/270/340/470/660
```

C. Fireplace Wood Usage Sector

The exact same code used in the Portland version of the model was used for Seattle, with the exception that 1977 fireplace wood usage was set at 100,000 cords/year. The value "100,000" replaced the Portland fireplace wood usage value of 209,000 in Model Lines 1710, 1712, 1716, and 1718.

D. Seattle Model Calibration

Calibration of the model for the Seattle area is more difficult because there is no complete survey of wood usage available. The available survey information consists of the following:

- o A Seattle City Light (private utility) survey which provides information on the number of fireplace and stove installations in all households in Seattle, but did not question respondents about the amount of wood they burn. The S.C.L. service territory is primarily composed of the city of Seattle.
- o A methodologically complete survey conducted by Del Green which provides good wood usage information for both stoves and fireplaces, but is questionably representative of the city of Seattle because it only surveyed 800 contiguous households within one neighborhood outside of the city limits.
- o A Puget Sound Power and Light Survey that provides information on the number of fireplace and stove installations in households, but did not question respondents about the amount of wood they burn. Further, the P.S.P.L. service territory covers all of King County excluding the Seattle City Light territory (and therefore excludes Seattle).

The primary purpose of this task was to project wood usage for Seattle. The projection was made by developing 1980 estimates of wood usage for the City of Seattle based on information from the first two surveys cited above. Future projections would be based on those values. The following section discusses in more detail how the 1980 wood usage estimates were derived from these two surveys.

Available survey information on wood usage in the Seattle area is incomplete. One private utility survey (Seattle City Light) provides information for an area slightly larger than the city of Seattle or the fraction of households with stoves and fireplaces but does not quantify wood usage per household. The survey conducted by Del Green provides the needed wood usage data but only covers 800 contiguous households in one neighborhood and is therefore questionably representative of even the city of Seattle. However, no better information is available. Wood usage estimates were derived using these two surveys and averaged in an attempt to minimize error. The categories of wood usage for heating purposes and "aesthetic" purposes are considered separately.

(1) Wood Usage for Heating Purposes

(a) Seattle City Light Survey

The S.C.L. Fall 1979 survey determined the number of households that 1) uses wood stoves/furnaces as a primary heat source, 2) use wood stoves/furnaces as a secondary heat source, and 3) use fireplaces with heatilators. Since no data is available on wood usage in these categories of households, the usage rates from the Del Green survey were applied yielding an estimate of wood burning for heating purposesas shown below.

Burning Unit	Seattle (City) Households	Seattle City Light Survey Based Fraction of Households with these units	Del Green Survey-Based Wood Usage Estimates (cords/HH/hr)	Resultants Wood Burning (cords/year)
Stoves-Primary Heat Source	220,000	.009	3.19	6316
Stoves-Secondary Heat Source	220,000	.033	1.58	11471
Fireplaces Heatilators	220,000	.041	2.94	26519
				44306 cords/yr

(b) Del Green Associates, Inc. Survey

The Del Green survey of a Bellevue neighborhood provided information on the fraction of households with wood burning units and on the amount of wood usage per unit. This information is shown following:

Burning Unit	1980 Seattle (City) Households	Del Green Survey-Based Fraction of Households with Units	Del Green Survey-Based Wood Usage (cords/HH/yr)	Resultant Wood Burning (cords/year)
Furnaces and Stoves-Primary Heat Source	220,000	.040	3.19	28072
Furnaces and Stoves-Secondary Heat Source	220,000	.032	1.58	28503
Fireplace with "insert"-Primary Usage	220,000	.019 -	2.94	12289
				68864

The average amount of wood burning in 1980 for "heating" purposes from these two surveys is 56,600 cords per year. Clearly, there is a lot of uncertainty remaining until a survey is conducted over a larger geographical area and requests information on both the types of units and amount of wood burned in those units.

Seattle City Light is planning another wood burning related survey in the summer of 1981. The utilities need this information if they are to develop precise estimates of how much their electric space heating load would be displaced by households relying on wood space heating. Air pollution agencies would be well advised to cooperate with the utility so that wood usage questions can be added to the survey. The agencies should desire this data to determine the amount of wood burned in stoves vs. fireplaces (since pollutant emission rates are different)

(2) Fireplace-Aesthetic Wood Usage

(a) Seattle City Light Survey

The S.C.L. Survey found that 26.7% of households in their service territory have fireplaces without any heatilators, etc. Based on the Del Green survey finding that such units burned about .7 cords/year, an estimate of fireplace wood usage of 41,100 cords is derived. The S.C.L. survey found that 4.1% of households they served had fireplaces with heatolators. Assuming the rate of usage from the Del Green Associates, Inc. survey (1.76 cords/HH/year) for these units affords an estimate of 15,900 cords/year. Thus, total fireplace wood usage is estimated to be 57,000 cords/year.

(b) Del Green Associates, Inc. Survey

The remaining three categories of wood burning from the Del Green Survey are shown below, together with wood usage estimates in those categories.

Burning Unit	1980 Seattle (City) Households	Del Green Survey-Based Fraction of Households with Units	Del Green Survey-Based Wood Usage (cords/HH/yr)	Resultant Wood Burning (cords/year)
Fireplaces - No Inserts, Primary Usage	220,000	.013	1.38	3947
Fireplaces-with Inserts Secondary Usage	220,000	.149	1.61	52776
Fireplaces-No Inserts Secondary Usage	220,000	.651	0.70	100254
Fireplaces with Inserts-Primary Usage	220,000	.019	2.94	12289
				169266

The average of these two survey-derived estimates is a fireplace wood usage estimate of 113,000 cords/year for the city of Seattle for 1980.

(3) Comparison of Model Predicted 1970-80 Wood Usage with Survey Results

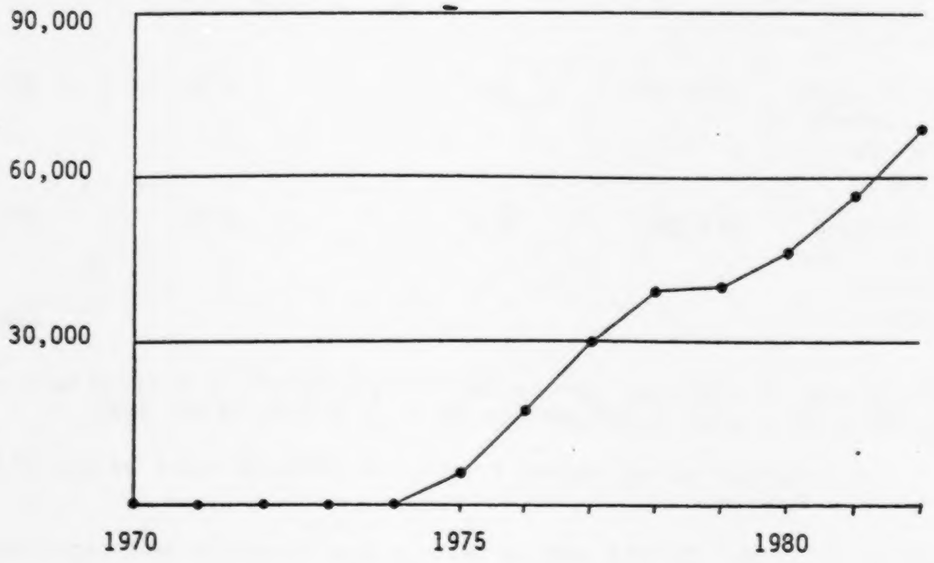
Local input factors such as Seattle area household heat requirements, fuel prices, etc. were input into the model. Additionally, several of the functions which are influenced by the annual heating requirements of an area were modified, as explained in Section 2b of this Appendix.

Based on the review of survey information, 1980 wood usage by the 220,000 households is estimated to be about 42,000 cords per year in stoves and furnaces and about 113,000 per year in fireplaces. The rate of wood usage for primary heating purposes appears to be lower in the Seattle area than in the Portland area. This is hypothesized to be largely due to Seattle's lower electricity rates (slightly over 20 mills/kwh vs. 37 mills/kwh in Portland in 1980). Figure 12 shows the best estimate of wood usage trends in Seattle City between 1970 and 1980[2]. There is an acceleration in wood usage between 1976 and 1980 as would be expected.

Based on input factors which are representative of Seattle area conditions, 1980 wood usage in stoves or for primary heating purposes was

FIGURE 12

Model Estimated Stove Wood Usage in Seattle City
1970 - 1982 (Cords/year)



predicted to be about 39,000 cords per year. The 1979 and 1981 wood usage in stoves is estimated by the model to be 57,000 and 57,000 cords/year, respectively. This prediction by the model was considered to be in agreement with the survey derived estimate of wood usage of 42,000 cords/year in 1980.

Regarding total wood usage, the annual growth rate projected by the model between 1979 and 1982 is 6% per year, which is consistent with the short term trend findings in Section 2 of this report. Stove, fireplace and total wood usage is shown in Figure 13.

Seattle City Light will be conducting another wood heating survey in the summer of 1981. If questions can be incorporated into the survey on wood usage rather than just on the fraction of households with stoves and fireplaces, the additional information should be of value to the utility (to project how much heat is being displaced by wood heating) as well as to air pollution agencies (interested in wood usage in fireplaces and stoves separately, because of their different emission factors).

(4) Base Case 1970-2000 Projected Wood Usage in Seattle City

The projections through the year 2000 indicate the Seattle total wood usage will increase about 20% in the 1980 to 1985 period, remain about constant through 1993 and decrease about 10% in the period following through 2000. The model projects a peaking of wood combustion in the latter 1980's with a decrease projected for the 1990-2000 decade, unlike the acceleration in wood usage projected for the Portland area for that period.

This is believed to be attributable to several factors:

- Seattle heating requirements are about 20% less than Portland reducing the potential savings from wood heating
- Similar electricity price escalation factors (from BPA) are applied for both cities, but the baseline 1980 rates are about 43% lower for Seattle. Therefore Seattle rates are about 43% lower in all future years. Households heating with electricity have less savings potential from heating with wood and therefore are less likely to convert to wood.
- Lesser population growth is projected for the Seattle area.

The model projections for wood usage in the Seattle area are shown in Figure 14.

Conclusions based on these projections are discussed in the Findings and Conclusions section of the text (Section III).

FIGURE 13

Model Estimated Wood Usage by All Appliances
in
Seattle Area, 1970 - 1982 (cords/year)

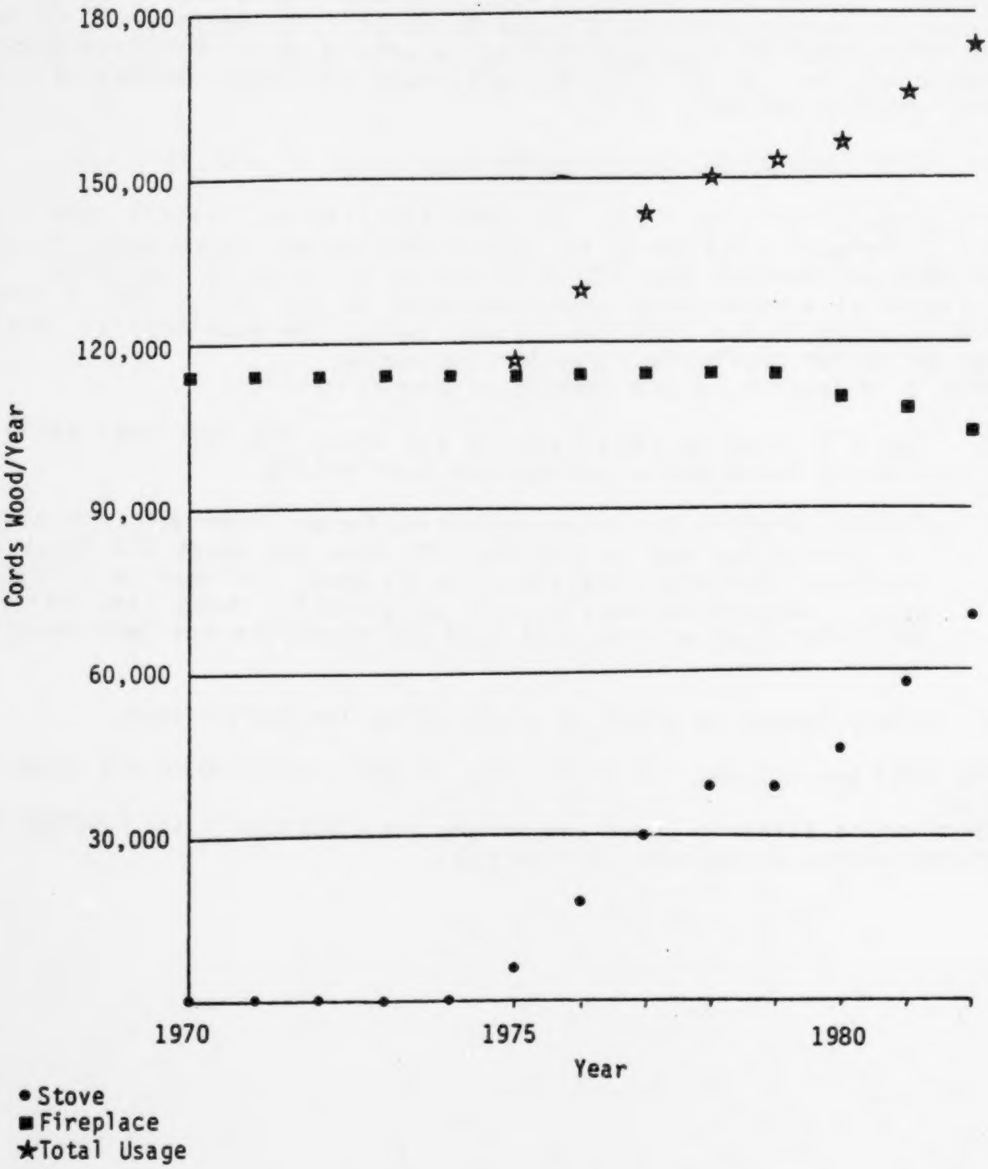
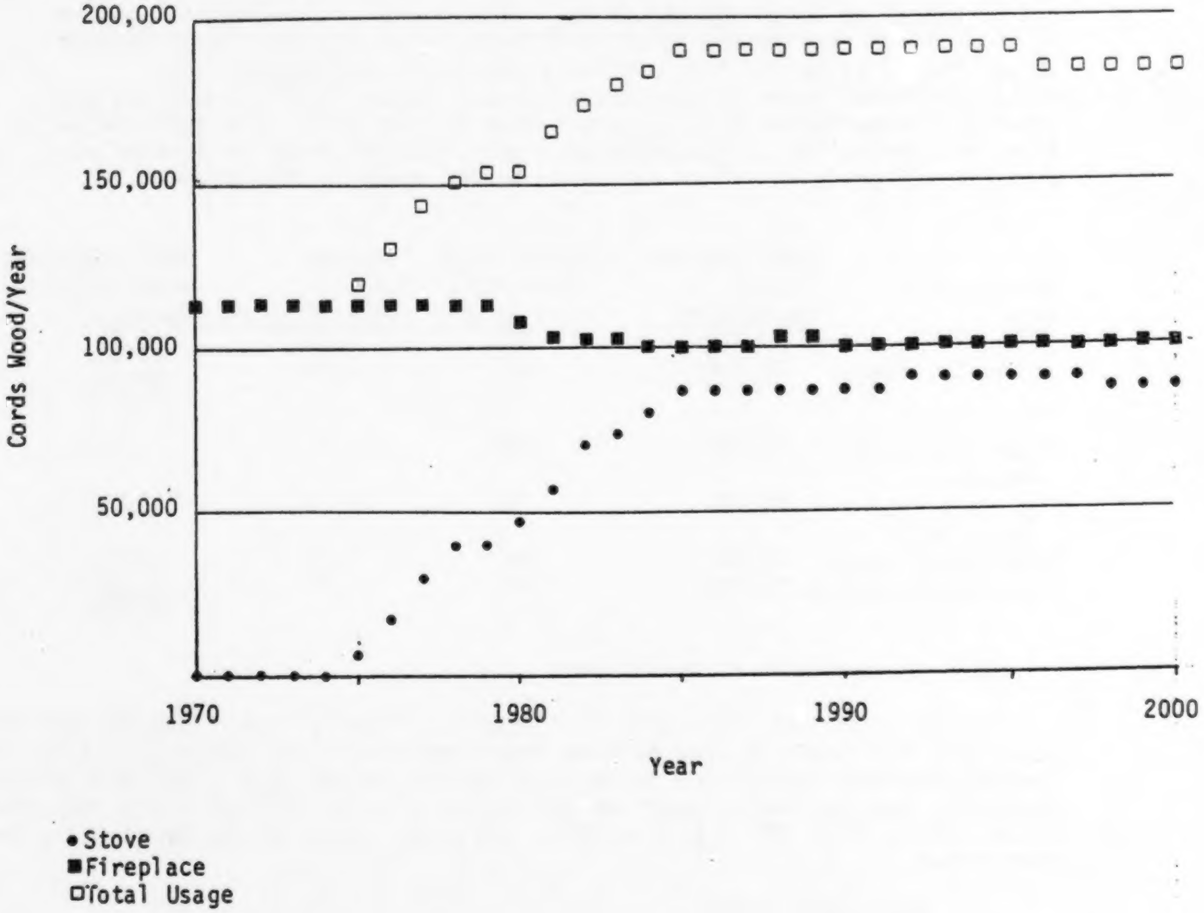


FIGURE 14

Base Case Model Projected Wood Usage
in
Seattle City, 1970 - 2000, (cords/year)



3. SPOKANE MODEL DOCUMENTATION

In order to fully understand this section, the reader is advised to first read the documentation for the Portland modeling work (in Appendix). To the extent that some model impacts for Seattle were also used for Spokane, the reader may also need to review certain sections of the Seattle documentation, but all these instances are specified in this section. This section explains only modifications that are different from the code used for either Portland or Seattle.

A. Local Condition Inputs

(1) Spokane Area Historical Wood Usage

Available survey information on wood usage in the Spokane area is incomplete. A Del Green Associates, Inc. survey is available covering one neighborhood in the Spokane area. Despite questions about the degree to which it is representative of conditions in the entire City of Spokane, it was judged to be the best available source of information. The Washington Water Power Survey covered a much larger territory and did not provide information on wood usage per wood burning unit. The table below shows the derivation of the estimates that 1980 wood usage in Spokane was about 26,000 cords in stoves and about 96,000 cords in fireplaces.

Burning Unit Type	1980 Spokane (City) Households	Fraction of Households With Unit	Average Use (cords/HH/yr)	1980 Resultant Wood Burning cords/yr)
Stoves-Primary	70,900	.025	4.98	8,827
Stoves-Secondary	70,900	.032	2.98	17,325
				26,152
Fireplace Insert Primary	70,900	.028	4.3	8,536
Fireplace Insert Secondary	70,900	.260	2.33	42,951
Fireplace/Primary	70,900	.059	2.37	11,594
Fireplace/Secondary	70,900	.503	.94	33,323
				96,404

(2) Household Heat Requirements

Since a direct estimate of household heating requirements was not available for Spokane, the Spokane requirement was estimated by ratioing Spokane heating degree days to Portland heating degree days. The 1970 initial household heating requirement ws estimated to 64.7 million BTU's per year ($6518/5035 \times 50 \times 10^6 = 64.7 \times 10^6$). This was input in the model using the code below:

```
890 C HRHI = 50E6
```

(3) Household Growth Function

Estimates of the number of households in the city of Spokane in 1970 and 1980 were available from U.S. Census Data. A 1975 value was derived by interpolation. For future year projections, the Spokane SMSA growth projections were applied to estimate growth in the number of households after 1980. The table following shows the household projections in Column 4 and the basis for projecting years 1985, 1990, 1995, and 2000 in Columns 2 and 3.

Year	SMSA Population Projections	SMSA Growth Relative to 1.00	Spokane City Number of Households
1970	NA		60442
1975	NA		65579
1980	337502	1.000	70916
1985	371000	1.099	77937
1990	399733	1.184	83965
1995	432529	1.282	90914
2000	470530	1.394	98857

The values in Column 4 of the above table were converted into annual growth rates for each of the five-year periods between 1970 and 2000 and input in the model via the code below:

```
300 T THGF= .016/.016/.019/.015/.016/.017/.017
```

(4) Initial Fraction of Households with Wood Heating

Data available from the 1970 Census of Housing indicated that .39% of households relied on wood as their primary heat source in 1970. This was input in the model using the code below:

```
270 C IFHWC = .0039
```

(5) Heating Requirements

Since Spokane area heating requirements were determined to be 129.4% of Portland requirements, the projections for how heat requirements will drop through the year 2000 were set at 129.4% of the Portland values, and the following code was input in the model.

```
1050 T THFH = 64.7/62.1/58.2/55.0/51.8/49.8/48.5
```

(6) Adjustment to Real Prices Based on the Consumer Price Index

All historical fuel prices were input into the model in 1980 constant dollars. Since year by year CPI figures were not available for the Spokane area, Seattle CPI figures were utilized. These were documented in the Seattle section of this Appendix.

(7) Historical Oil Prices

The Oil Heat Institute of Washington stated that historical oil prices for Spokane and Seattle were essentially the same. Thus, the same code was used for Spokane as for Seattle for historical oil prices.

(8) Historical Gas Prices

Historical gas prices in the Spokane area were obtained from Washington Water Power and are shown in Column 2 of the following table. Gas prices in 1980 dollars were derived by the CPI, and the resulting historical real prices for gas are shown in Column 3 below.

Year	Actual Gas Price (\$10^6 BTU)	Real 1980 \$ Gas Price (\$/10^6 BTU)
1970	1.07*	2.24
1971	1.165*	2.40
1972	1.165*	2.31
1973	1.222*	2.34
1974	1.737*	3.02
1975	2.079	3.23
1976	2.650	3.87
1977	2.754	3.79
1978	3.033	3.89
1979	3.947	4.61
1980	4.478	4.48

*Rates changed after first 65 therms used in a month

The values from Column 3 above were input in the model using the code below:

```
    1260 T TCPI = 2.24/2.4/2.31/2.34/3.02/3.23/3.87/3.79/3.89/4.61/4.48
```

(9) Historical Electricity Prices

Historical electricity (actual) prices were obtained from Washington water power and are shown in Column 2 below. Prices in real 1980 dollars were derived using the CPI and are shown in Column 3.

Spokane Area Historical Electricity Prices

Year	Actual Electricity Price ($/kwh)*	Real 1980 Electricity Price ($/kwh)
1970	.0096	.0201
1971	.0096	.0198
1972	.0096	.0190
1973	.0101	.0194
1974	.010	.0174
1975	.0107	.0165
1976	.0107	.0156
1977	.0107	.0147
1978	.0130	.0167
1979	.0145	.0185
1980	.0145	.0145

*In some years, rates change with level of usage. 2000 kwh monthly electricity usage for heating was assumed.

The values in Column 3 were input in the model using the code below:

```
1350 T TEPA = .0201/.0198/.019/.0194/.0174/.0166/.0156/.0147/.0167/.0186/.0145
```

(10) Historical Wood Prices

Actual historical wood prices were obtained from the Spokane Herald for years 1970, 1975, and 1980. The values are shown in Column 2 below. These prices were converted to real 1980 dollars using the CPI and intermediate year estimate derived by interpolation. Estimated historical wood prices in real prices are shown in Column 3.

Year	Actual Price ($/cord)	Real Price (1980 $) ($/cord)
1970	25	54
1971		56
1972		58
1973		61
1974		64
1975	43	66
1976		67
1977		68
1978		68
1979		69
1980	70	70

(11) Historical and Projected Fuel Split

The 1970 census of housing provided information on the distribution of oil, gas, and electricity usage (as the primary heat source) in occupied housing units. For 1980, there is no survey information that has geographical coverage comparable to Spokane. The Del Green Survey results cover an area of 300 contiguous households and a utility survey by Washington Water Power provides information for an area larger than the SMSA. The fuel splits from these two information sources are significantly different, and there is fuel split information on an SMSA basis for both 1970 and 1977. The table below shows the different fuel splits which are available for years 1970 and 1980.

Spokane Area Fuel Splits (relative to 1.00)

Source	Year	Area Coverage	Oil	Gas	Electricity
Del Green Survey	1980	Neighborhood in Spokane	.084	.832	.084
Washington Water Power Survey	1980	Larger than Spokane SMSA	.24	.39	.23
Census	1970	Spokane City	.43	.47	.10
Census	1970	Spokane SMSA	.40	.44	.16
Census	1977	Spokane SMSA	.287	.421	.292

Two methodologies were employed to develop 1980 fuel splits for Spokane. First the Del Green and Washington Water Power splits for 1980 were averaged. Second, the assumption was made that the SMSA trends between 1970 and 1977 also occurred in Spokane. This trend was extrapolated through 1980. The first two rows in the table following show the splits derived by these two methods. Note the electricity heating share is about the same. This minimizes concern about developing the correct splits since oil and gas prices tended to increase over the 1970-1980 period at similar rate. The model calibration of heating costs are not that different when different oil vs. gas splits are input. For the assumed 1980 fuel split in Spokane, the first two rows in the table were averaged and assumed to represent the 1980 Spokane fuel split. 1975 values were derived by interpolation.

Source	Year	Oil	Gas	Electricity
Average of Del Green & WWP	1980	.16	.61	.23
Spokane City projected to 1980 based on 70-77 SMSA Trends	1980	.28	.48	.24
Average of Above Two Estimates	1980	.22	.545	.235

For future year fuel split projections, the only source obtained for the Pacific Northwest was ODOE projections for the future fuel splits for the state of Oregon. Based on how oil, gas, and electricity usage is projected to change in Oregon from 1980 to 2000, the Spokane area splits were projected to change in the same proportion by 2000. The year 2000 derived split was normalized to sum to 1.00 and values for years 1985, 1990, and 1995 derived by interpolation. The 1985-2000 values are shown in rows 4 through 7 in the table below.

Historical and Projective Spokane City Fuel Splits
(Relative to 1.00)

Year	Oil	Gas	Electricity
1970	.43	.47	.10
1975	.325	.508	.167
1980	.22	.545	.235
1985	.203	.543	.254
1990	.186	.541	.272
1995	.169	.539	.291
2000	.152	.537	.309

Only the values for oil and gas are input into the model, with electricity shares derived by difference. Lines 1080 and 1100 impact the oil and gas splits in the model, respectively, as shown in the code below:

```
1080 T TFCFO = .43/.325/.22/.203/.186/.169/.152
1100 T TFCFG = .47/.508/.545/.543/.541/.539/.537
```

(12) Future Oil and Gas Prices

Future oil and gas prices were based on real price growth projections for the Pacific Northwest by BPA. These projected real prices are shown in the table below. Values are shown in 2.5 year increments to be consistent with model input requirements.

Projected Spokane Area Oil and Gas Prices

Year	Real Oil Price (1980 $/gallon)	Real Gas Price (1980 $/$10^6$ BTU)
1980	1.079	4.48
1982.5	1.200	5.18
1985	1.343	5.89
1987.5	1.430	6.45
1990	1.538	7.01
1992.5	1.665	7.65
1995	1.812	8.30
1997.5	1.880	8.98
2000	1.964	9.66

The data in Columns 2 and 3 above is input into the model using the code below:

```
1190 T TOPZ = 1.079/1.2/1.343/1.43/1.538/1.665/1.812/1.880/1.964

1230 T TGPZ = 4.48/5.18/5.39/6.45/7.01/7.65/8.30/8.98/9.66
```

*BPA, Economic, Demographic Projection of the Pacific Northwest, op. cit., p. 147.

BPA Electricity Price Growth Rates and Resultant Spokane Projections

Year	Growth Rate Projections for Public Utilities (1980=1.000)	Spokane Area Projected Real Electricity Prices ($/kwh)
1980	1.000	.0145
1982.5	1.078	.0156
1985	1.155	.0167
1987.5	1.291	.0187
1990	1.427	.0207
1992.5	1.473	.0214
1995	1.519	.0220
1997.5	1.5825	.0229
2000	1.646	.0239

The values in Column 3 are input in the model using the code below:

```
1370 T TEPZ = .0145/.0156/.0167/.0187/.0207/.0214/.0220/.0229/.0239
```

*BPA, Pacific Northwest Electric Energy Model, op. cit.

(14) Future Wood Prices

As for the other cities in the projection study, a 2% real wood price escalation factor was assumed and results input in the model using the code below for years 1980 through 2000 in 2.5 year increments:

```
1470 T TWPZ = 70/74/78/82/86/90/95/100/105
```

B. Explanations of Table Functions Adjusted

Only two of the "relationship table functions" were changed for the Spokane runs. Since heat requirements are lower, the same stove installation represents installation of a higher fraction of potential wood heating capacity (closer to 1.00). Thus, for a given fraction of capacity installed (i.e., 60% of household heating requirements) the inconvenience of wood heating should be slightly lower for that fraction of capacity and the wood stove installation cost slightly lower (as compared to the wood use and stove size needed to provide 60% of heating requirements in Portland or New England). The two functions changed were TCIWC and TNWIC.

(1) Cost of the Inconvenience of Wood

This function expresses how the cost of the inconvenience of wood due to capacity increases as the capacity fraction installed increases. As explained for TCIWC in the Portland section of the Appendix, the New England table values were simply ratioed downward in proportion to the ratio between Spokane household heating requirements (64.7 x 10^6 BTU's/year) and New England heating requirements (100 x 10^6 BTU's/year) in 1970.

The resultant code is shown in Line 1000 below:

```
1000 T TCIWC = 129/194/324/518/647/647
```

(2) Normal Wood Installation Cost (TNWIC)

Since heat requirements are less, the size of stove, and therefore cost, that must be purchased to provide 100% capacity is therefore less. The cost of 100% capacity was adjusted by the ratio of Spokane to New England Heating Requirements (\$1500 x 64.7/100), and the cheapest stove available was still assumed to be \$200. Intermediate values were interpolated based on the proportions in the original New England function. The resultant code is shown in Line 480 below:

```
480 T TNWIC = 200/259/317/434/670/970
```

C. Fireplace Wood Usage Sector

The exact same code as used in the Portland and Seattle versions of the model was used for Spokane, with the exception that 1977 fireplace wood usage was set at 100,000 cords/year. The value "100,000" replaced the Portland fireplace wood usage value of 209,000 in Model Lines 1710, 1712, 1716, and 1718.

D. Spokane Model Calibration

(1) Wood Use Survey Information

Calibration of the model for Spokane is more difficult than for Portland because no complete survey of wood usage is available. Two surveys with potential were available and these included:

- A Del Green Associates, Inc. survey[17] of a neighborhood in Spokane with information produced on the amount of wood usage in each of six different appliance categories. The chief problem with this survey is its questionable representativeness of Spokane because the sample is from geographically small area.
- A Washington Water Power wood usage survey[19] for a large service territory including Spokane. The two chief problems with this survey are: 1) wood usage information is only available in terms of the "fraction of households relying on wood as the primary heat source"; and 2) the "Spokane" division of WWP's service territory is three times as large as the population in Spokane.

Given these shortcomings in applicability for the utility survey, 1980 wood usage estimates were based on the Del Green Associates, Inc. survey results. Projections were for the city of Spokane as originally required since there was no good AQMA scale data base. The resultant estimate is that stove/furnace wood usage was 26,000 cords/year and fireplace usage was 96,000 cords/year in 1980. Appendix A discusses the derivation of these values for Spokane based on survey information.

(2) Comparison of Model Predicted 1970-1980 Wood Usage with Survey Results

Figure 15 shows the model-generated estimate of wood usage in Spokane between 1970 and 1980. There is an expected acceleration in wood usage between 1976 and 1980. Based on input factors, which are representative of Spokane conditions, 1980 wood usage was predicted by the model to be about 28,000 cords/year. Given the derived estimates of 1980 stove wood usage of 26,000 cords/year and the model prediction of wood use acceleration between 1976 and 1980, the Spokane version of the model was considered to be calibrated.

Regarding total wood usage, the annual growth rate projected by the model between 1979 and 1981 is 6.4% per year, which is quite consistent with the short term trend findings in Section II of this report. Stove, fireplace and total wood usage between 1970 and 1982 is shown in Figure 15. Fireplace usage is set at 96,000 cords/year initially.

(3) Base Case 1970-2000 Projected Wood Usage in Spokane

Projections through the year 2000 predict that total wood usage will level in the early 1980's and begin to decrease in the latter part of the 1980's (about 1986) at about a -.8% annual rate through the year 2000. This is believed to be attributable to several factors:

- Spokane electricity rates are still low relative to most other locations. For example, 1980 and 1981 rates at 2000 kwh/month were 1.45 and 1.98C/kwh. When BPA escalation factors are applied, future electricity prices are lower relative to other areas, and the savings potential from wood heating is less.
- Regional population growth between 1980 and 2000 is projected to be 39% compared to 56% for the Portland metropolitan area. If Spokane were to grow by 56% between 1980 and 2000, its total wood use would be projected to remain essentially constant between 1980 and 2000.

The model projections for wood usage in Spokane are shown in Figure 16.

FIGURE 15

Model Estimated Wood Usage by All Appliances
in
Spokane, 1970 - 1982 (cords/year)

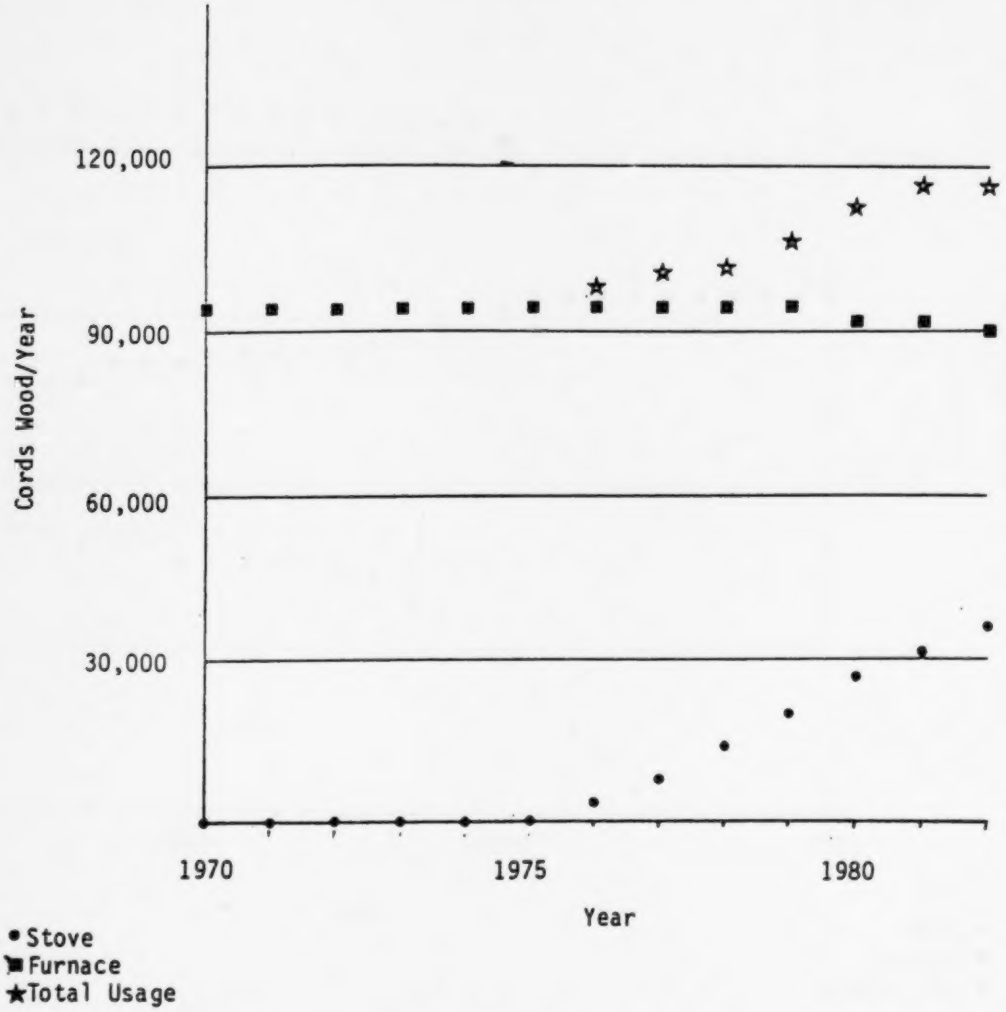
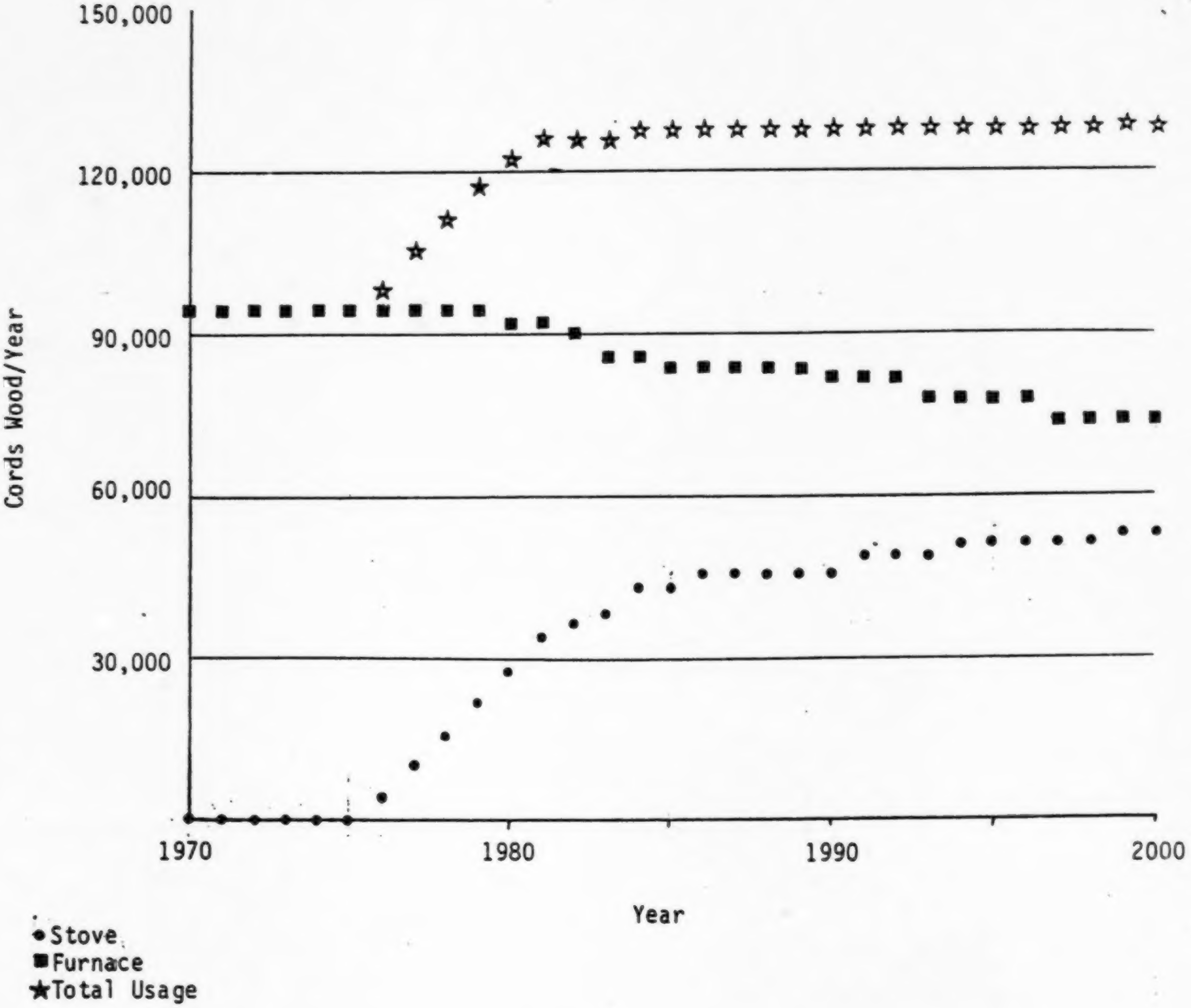


FIGURE 16
Base Case Model Projected Wood Usage
in
Spokane City, 1970 - 2000 (cords/year)



APPENDIX B

Major Factors Not Included in Marshall's Model

Marshall's model is driven to a large extent by the relative costs of the different energy forms. A number of other factors not included in the model can substantially affect wood burning levels. These include limitations on wood supply, the effect of conservation, and possible government actions affecting wood burning levels.

Marshall recognized that one of the weaknesses of his model is a lack of input for factors influencing wood supplies. Predicting the demand placed on wood residues from competing users, the resultant prices each could pay, and the interaction of the competing uses would in itself require substantial research which was beyond the scope of Marshall's study on New England and the scope of this study. Marshall (for New England) and the authors of this document chose a 2%/year real increase in fuel wood prices, which approximately corresponds with the expected increase of conventional fuels. Information follows on factors influencing wood supplies for the readers' further understanding of this topic.

Availability of Wood Resources

In order to assess the feasibility of a 50 megawatt wood-fired power plant in the Pacific Northwest, the Bonneville Power Authority conducted a literature review of timber supply data to develop estimates of logging residues available in 14 geographical areas within Oregon and Washington. This work represents the best available estimate of logging residues which could be available for use in residential stoves and fireplaces. Figures 17 and 18 show the annual availability of those logging residues as estimated in 1980 for the states of Oregon and Washington.

Over the next 20 years, the utilization of much of the remaining old-growth timber stands and the increased reliance on young-growth stands is

FIGURE 17

Oregon Unused Wood Residue Quantities[47]
(Annual Quantities in Dry Tons)

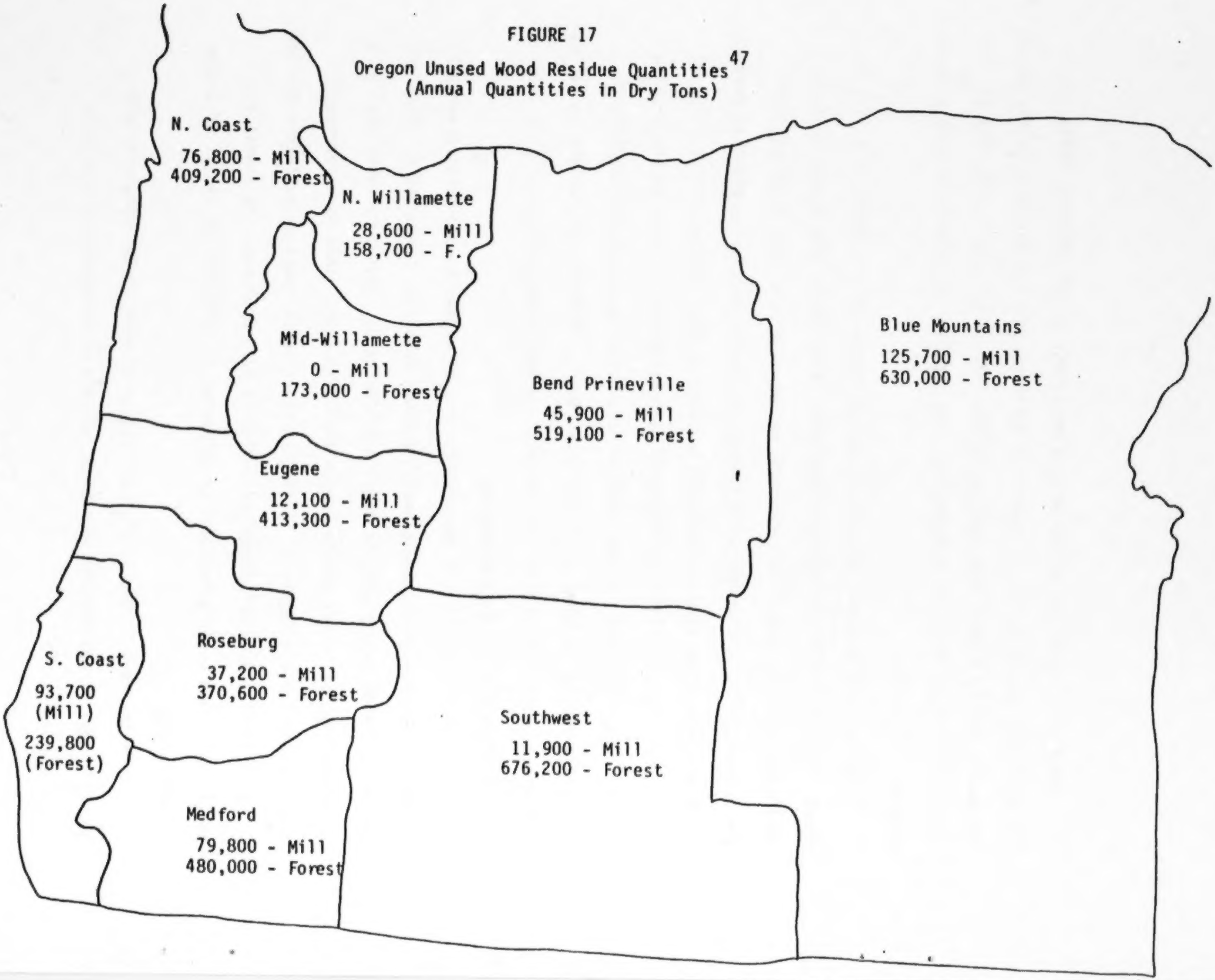
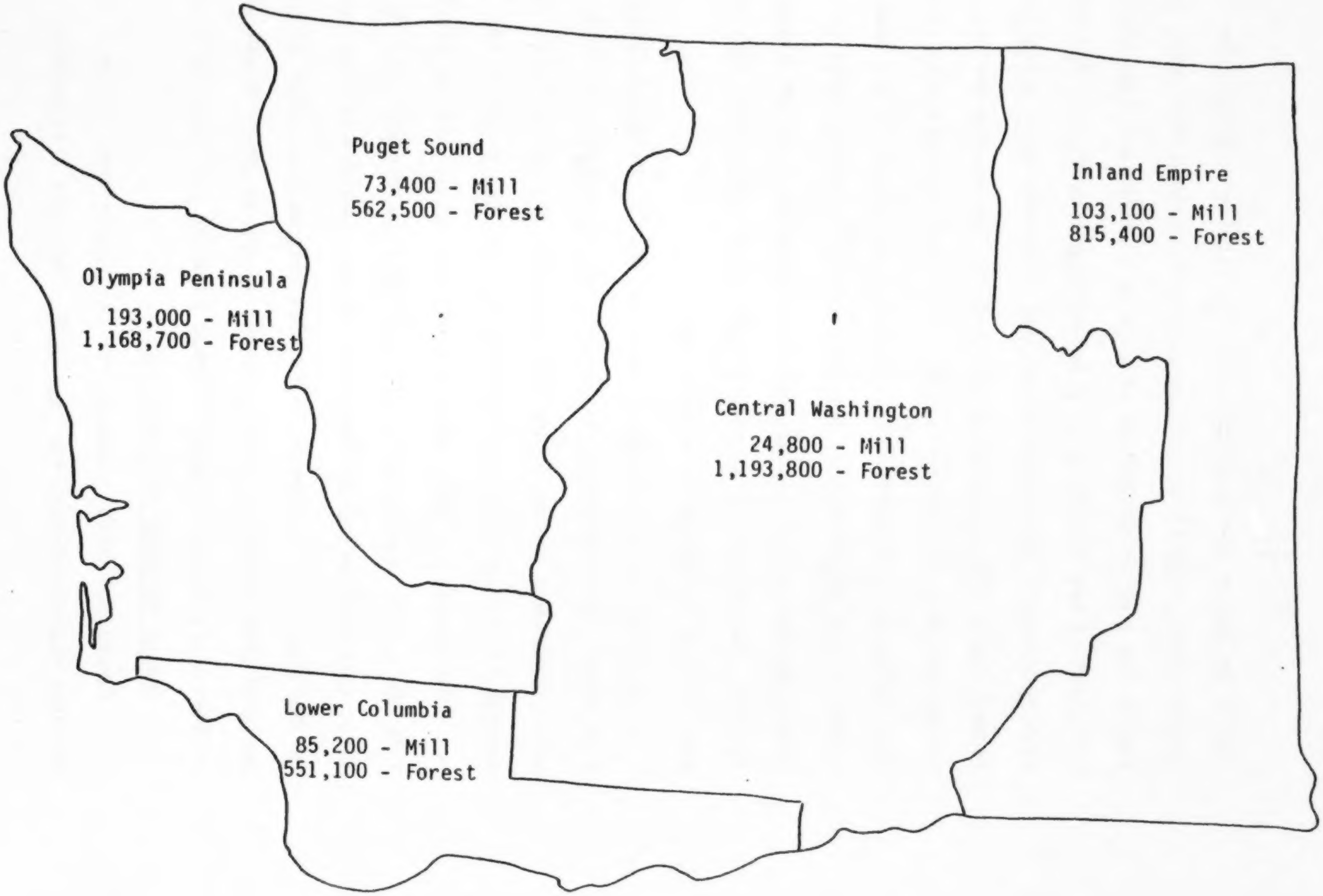

N. Coast
76,800 - Mill
409,200 - Forest
N. Willamette
28,600 - Mill
158,700 - F.
Mid-Willamette
0 - Mill
173,000 - Forest
Eugene
12,100 - Mill
413,300 - Forest
Bend Prineville
45,900 - Mill
519,100 - Forest
Blue Mountains
125,700 - Mill
630,000 - Forest
S. Coast
93,700
(Mill)
239,800
(Forest)
Roseburg
37,200 - Mill
370,600 - Forest
Southwest
11,900 - Mill
676,200 - Forest
Medford
79,800 - Mill
480,000 - Forest

FIGURE 18

Washington Unused Wood Residue Quantities[47]
(Annual Quantities in Dry Tons)


Puget Sound
73,400 - Mill
562,500 - Forest
Inland Empire
103,100 - Mill
815,400 - Forest
Olympia Peninsula
193,000 - Mill
1,168,700 - Forest
Central Washington
24,800 - Mill
1,193,800 - Forest
Lower Columbia
85,200 - Mill
551,100 - Forest

likely to reduce the available mount of logging residues. Harvesting old-growth stands results in considerably more residue than young-growth stands due to the greater percentage of wood in branches and tops and because the old-growth trees did not grow under managed conditions. According to the Washington State Department of Natural Resources' Wood Waste for Energy Study[42], second growth timber stands generate 70 to 90% less forest residues during harvesting than old growth stands. This could be partially offset by wood from intensified management of second growth stands (i.e., wood from thinnings). A 1980 Oregon Department of Forestry report[43] projects that while 46% of Oregon's timber harvest volume was derived from trees of 21 inches diameter or greater in 1980, the percentage of the harvest volume from this class of trees in the year 2000 is projected to be only 26%.

A potential counterbalancing trend may be increased removal of firewood from forest lands held by individuals. As an example, in 1979, a pilot fuel wood program was tested in New England under the Agricultural Conservation Program of the Agricultural Stabilization and Conservation Service[44].

Assistance was used to mark trees for cutting and to provide access roads into the stand. Landowners could then sell the marked trees for firewood. The first year program was so successful it was expanded to five states in 1980 and further expansion is planned. The 1980 program cost about $2 million and produced some 250,000 tons of firewood, which is about $8 per cord. This sort of program could result in more firewood becoming available in the Pacific Northwest.

Demand for Wood for Other Uses

Demand for forest products for uses other than firewood is projected to increase rapidly through the year 2000. The most comprehensive set of projections for these other uses are presented in the US Forest Service document entitled An Analysis of the Timber Situation in the United States 1952-2030[45]. A summary of the projected demand for various end uses of wood is shown in Table 41.

TABLE 41

Projected U.S Growth in Demand
for
Various Timber Products, 1976-2000

	Lumber (10^9 bd.ft.)	Plywood (3/8" basis, 10^9 sq. ft.)	Fiberboard (3/8" basis, 10^9 sq.ft.)	Other Fibrous Materials 10^6 tons	Roundwood (10^9 cu.ft.)
1976	42.7	20.6	13.5	60.2	13.3
2000	59.9	30.0	25.3	121.5	22.7
% Increase	40%	46%	87%	102%	71%

These projections indicate that unless total wood supplies are greatly expanded, there will be increasing competition among the various end uses of wood that compete with the use of wood for firewood. The largest increases are projected for those wood uses (fiberboard and other fibrous materials) that compete most strongly with firewood because they can utilize wood residues and mill wastes.

At the Third Annual National Biomass Systems Conference in 1979[41], Charles Hewett noted that "The depletion of old growth timber (stands in the Pacific Northwest) will increase the demand for the production of particle boards, fiberboards, and similar products as substitutes for lumber and plywood. Indeed, the production and consumption of such products is already rising rapidly (USDA 1973, USDA 1979). The raw materials for these products are very similar to the wood fiber used for energy production. With the rapid development of new processes for the production of these materials, the forest products industry will obviously compete increasingly with the wood-energy market during the next thirty years."[41] Unfortunately, Marshall's model does not take into account the effect of limited availability of fuel wood because of competition by other users.

Conservation Measures That Reduce Home Heating Energy Demands

A variety of actions can be undertaken to reduce household heating demand. Since the driving force behind the conversion of household heating systems to wood heat is the desire to reduce space heating costs, these various conservation actions can reduce the need and desire of households to switch to wood to save money. These actions can be grouped into four major categories:

- Household Weatherization
- Fireplace Modification
- Localized Room Heating
- Humidification

Weatherization

Household weatherization, which includes actions such as increased insulation of roofs, walls and flooring, double and triple window glazing, weatherstripping and caulking, can reduce household air leaks and thereby the amount of energy required to maintain comfortable temperatures. The Portland Energy Office cites reductions in space heating of 30 to 50% as achievable for poorly insulated homes[55]. In the Oregon Department of Energy's publication Weatherization, One Step At A Time[56], Governor Victor Atiyeh states that "60% of Oregon's homes are poorly insulated. If all our homes were properly protected from heat loss, we could cut our household heating requirements by as much as 30%".

For new homes with the most sophisticated weatherization technology, the reduction in space heating requirements that is achievable is astounding. A January 1981 article in Canadian Energy News cites weatherization techniques that can reduce annual heating costs in 9000 degree-day climates to under $100 per year[57].

Although weatherization can significantly reduce heating costs, a significant deterrent to implementation of weatherization actions are the initital costs, which often exceed $1000. Even though this weatherization investment can produce permanent savings after a reasonably short payback period, many homeowners tend to compare the initial weatherization costs to the annual costs of continuing to heat without weatherization rather than comparing these two costs on an appropriately discounted basis. Several utilizites and municipalities throughout the Pacific Northwest have established grant and low interest loan programs to help overcome individuals' aversion to high initital first costs. Some of these programs are described following:

- City of Portland

The City of Portland adopted an Energy Conservation Policy on August 15, 1979. Energy planners estimate that successful implementation of all components of the plan will result in a city-wide energy savings potential of 25-35% of the present level of energy consumption by 1995. The most controversial and progressive feature of the plan is the requirement that residences must be insulated to cost effective levels before than can be resold, starting in 1984, and subject to voter approval of this requirement.

The plan contains six major policies, one of which is the retrofit program for the residential sector. This program establishes a "one-stop" conservation center which conducts an aggressive energy conservation marketing program entitled the Energy Savings Center. The center is operated by a private non-profit corporation that acts as a clearinghouse, coordinating information and promoting participation in weatherization services to individuals residing within the city limits.

In a typical Portland home, space heating consumes about 72% of the total energy used, and a reduction in heating requirements of 60% can be achieved if the structure is insulated and weatherproofed. The initial stages of the retrofit program are optional and are accomplished through voluntary participation; mandatory requirements for cost effective* weatherization are scheduled to take effect in 1984, subject to voter approval. However, meeting the weatherization requirements will then be obligatory only at the time a home is sold. The owner will verify to the buyer than an energy audit and the necessary work has been completed.

The City's low interest loans are currently obtainable at 8% interest through a $3 million U.S. Department Housing and Urban Development Action Grant. These funds are matched locally with $14 million dollars from local lending institutions.

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* Cost effectiveness standards have been determined to ensure that the cost of weatherization combined with monthly fuel bills is no more than what was previously paid for fuel alone.

- City of Seattle

Seattle City Light formed Seattle Home Insulation Program Office to coordinate weatherization, energy audit, and financing information. The Seattle program affects residential structures of 1-4 units. It emphasizes electrical energy conservation but affects homes with other heat sources as well. Seattle estimates average costs of about $1200 per home. Zero interest loans are provided by Seattle City Light for electrically-heated homes with low interest loans for homes heated by other fuels.

Seattle requires attic ventilation and R-30 attic insulation, ground vapor barrier and R-19 floor insulation, waterheater jacket and thermostat setback (130 degrees F), and insulated ducts and pipes in unheated spaces. Seattle encourages caulking and weatherstripping, wall insulation and thermal or storm windows. Seattle will review the progress of the voluntary weatherization program in 1983 to determine if the mandatory program is necessary.

Fireplace Modification

Fireplaces without glass doors or other covering mechanism can have negative efficiency because large quantities of heated air can escape up the flue during nighttime hours. For example, if a fireplace fire burns between 5:00 P.M. and 11:00 P.M., the chimney damper typically cannot be shut until about 3:00 A.M. or smoke from the dying fire will be forced into the dwelling. Thus, for a fireplace without glass doors or similar device, heated household air will escape up the flue all night long while little heat is produced by the smoldering logs.

For fireplaces without glass doors, negative efficiencies are often cited because of this nighttime heat loss phenomenon. The addition of a fireplace face-covering system can increase efficiencies to the 10 to 20% range.

Localized Room Heating

Most dwellings in the Pacific Northwest are heated by central heating units. When room heaters are used, individuals can stay comfortable in the heated room without the necessity of heating the air volume of the entire dwelling. This practice is commonly employed with wood stoves where a resident is willing to accept cooler temperatures in portions of the dwelling if the rooms most commonly used are maintained at comfortable temperatures.

Other equipment, however, can be used to achieve similar effects by applying heat selectively in a household. For example, the use of electric blankets can make cooler bedroom temperatures much more acceptable, and the use of electric heaters or heat lamps in bathrooms can reduce the need to maintain an entire dwelling at 68 degrees to 72 degrees F temperature.

A phenomenon similar to the expansion in wood stove purchases is now occurring with kerosene room heaters. These room heaters are commonly placed in main living areas and maintain comfort there without the entire house being heated to those levels. A February 1, 1982 Time magazine article[66] states that about 3 million households will use these kerosene room heaters in winter 1981-1982 and that 8 to 10 million households are expected to utilize these units by 1985. Concern about safety of unvented kerosene heaters may limit the widespread use of these units. Such units are illegal in Oregon under the Oregon Uniform Mechanical Code, State Fire Marshal.

Humidification

Humidification of the air inside a dwelling can make cooler temperatures feel much more acceptable. Heating efficiency can be added to by increasing the humidity inside the home. Cold air has very little water retention capability, so during winter, warmed air is very low in relative humidity, often under 15%. For comfort, some method of adding moisture to home air can help significantly. A house with a 68 degree temperature and a relative humidity of 15-20% may feel unpleasantly cool, even without drafts. Raising the relative humidity to 35% may make the same temperature feel comfortable.

The most efficient way to humidify a wood-heated home is with the small electric powered humidifiers. The basic units typically sell for about $100. Humidifying is a simple job for wood stoves with flat tops. One or two saucepans two-thirds full of water can be placed on top of a stove.

Relevant Government Policies

Government policies will influence the future level of residential wood usage by actions that make wood supplies either more or less available or expensive, by actions that effect the cost of alternate residential fuels and by actions that affect household heating requirements. For organizational purposes, government policies are discussed in the following categories:

- Forestry Agency Policies
- Policies Influencing Household Heating Costs

Forestry Agency Policies

- Allocation of Forest Resources for Firewood

The bulk of this discussion focusses on Federal agency policies since these agencies manage the vast majority of all forested government lands. For example, in Oregon, US Forest Service and Bureau of Land Management lands account for 84% of the current harvest on public lands[50].

The Multiple-Use, Sustained-Yield Act of June 12, 1968 established that the national forests shall be administered in a manner meeting a variety of objectives, including outdoor recreation, range, timber, watershed, and wildlife and fish purposes. No specific weighting of these different purposes is directed. Instead, the Secretary of Agriculture is "directed to develop and administer the renewable surface resources of the national forests for multiple use and sustained yield of the several products and services obtained therefrom". Thus, there is a fair amount of flexibility allowed in the US Forest Service policies.

The particular policy issue which may become an important influence on future residential wood usage is whether government agencies will allow free or low-cost cutting of firewood on Federal lands or whether these amounts of wood will ultimately go to other uses such as in industrial or utility boilers or for fiber or forest products, which can also utilize logging residues. Although there is no stated US Forest Service policy to indicate how the US Forest Service will allocate residues among the potential users, several US Forest Service employees contacted in the course of this study noted that historically there is a tendency to allocate the forest resources towards products rather than for fuel purposes.

The precedent for allowing free cutting of firewood on US Forest Service lands is found in the Forest Service Management Act Part 223.1 (Authorization for Sale and Disposal of Timber) part (3)[31]. Free use of firewood is authorized for certain individuals and "supervisors" are granted authority to designate portions of forest lands for personal use or domestic reasons.

The management of US Forest Service lands for energy purposes is addressed in Chapter 2170 (Energy, Management), amended in April 1980. Under Section 2170.24, the US Forest Service is directed to:

> "Improve the Nation's energy alternatives by facilitating recovery of critical fuels from forest lands and implementing programs to support production and use of alternative fuels."

Responsibilities for planning and implementation activities are delineated, but again, there is no specific directive on how much of the forest resources should be allocated for energy programs or how wood products for energy purposes should be allocated among potential residential, commercial, or industrial users.

In conversations with US Forest Service employees, they indicate that future allocation of wood resources will most likely be dependent on the market value of wood for different purposes. Several changes can be foreseen which may increase the demand for logging residues for purposes other than for residential wood combustion. These factors include 1) the trend toward more complete utilization of trees by products firms; and 2) the potentially greater value of forest products for energy conservation when used as products rather than fuel.

Up to 1974, forest product firms removing timber from US Forest Service lands were required to remove the portion of trees only over eight inches in diameter. The tops of trees and branches with lesser diameter were typically left behind as logging residues and burned as slash. The policy[54] changed this requirement to six inches diameter and a further reduction to requiring removal of logs down to four inches diameter is scheduled to take effect in 1985. As less and less of individual trees is left behind in forests, less wood may be available for individuals to cut for firewood purposes.

Several references in the literature note a greater value of wood products for energy conservation when used as products rather than as fuels. For example, Dr. F. Bryan Clark, US Forest Service Associate Deputy Chief for Research states it takes 8 to 9 times as much energy to produce a ton of steel as a ton of wood products[44]. David M. Smith, Professor of Silviculture at Yale has noted, "The most important way of using wood for energy conservation is as a structural material. While it is both valuable and important to use more wood as fuel, this is really only the second-best way of employing wood to save energy"[52]. Thus, government agencies may opt to preferentially allocate forest raw materials to purposes other than as fuel over the next 20 years.

Counterbalancing these forces may be individuals wanting to continue to burn wood for residential heating because of its aesthetically pleasing qualities and heating value. The following extract from an August 1979 editorial in the Salem (Oregon) Capital Journal is illustrative. The editorial closes:

> "The Forest Service has seen enough evidence by now that poeple want all the firewood they can get. It is up to the agency to meet those needs in the most efficient manner possible." [53]

- Allowable Time Period of Cutting

Government agencies typically allow firewood cutting on forest lands between April through June and September through November. Many individuals attempt to burn wood that has been cut in September through November during the winter season immediately following. This is generally an insufficient period to "season" or dry to proper moisture levels.

Policies Influencing Household Heating Costs

The major factor influencing households to use more wood for space heating is the potential savings achievable as compared to heating with conventional fuels[57]. Accordingly, government policies that effect conventional fuel prices for residential heating can affect the relative fuel costs, therefore the proclivity to use more and more wood for heating.

Inverted electricity rate structures have been adopted by many utilities in the Pacific Northwest in recent years. If federal agencies were to adopt legislation reducing the costs of conventional fuels purchased for residential heating, there would be less incentive for using wood. However, the current trend towards lesser federal regulation and greater reliance on free market forces would indicate that such actions are not likely to occur in the near future.

A second means by which households heating costs can be reduced is by vigorous weatherization of dwelling structures. Weatherization can reduce a household's heating requirement as much as 60%. Thus, future government policies to promote weatherization such as tax credits, grants, and low interest loans have the potential to dramatically cut average heating costs, which would result directly or indirectly in less wood consumption.